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PROJECTED AND PAST EFFECTS OF CLIMATE CHANGE: A FOCUS ON MARINE AND TERRESTRIAL SYSTEMS

HEARING

BEFORE THE

SUBCOMMITTEE ON GLOBAL CLIMATE CHANGE AND IMPACTS

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

ONE HUNDRED NINTH CONGRESS

SECOND SESSION

APRIL 26, 2006

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SECOND SESSION

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PROJECTED AND PAST EFFECTS OF CLIMATE CHANGE: A FOCUS ON MARINE AND TERRESTRIAL SYSTEMS

WEDNESDAY, APRIL 26, 2006

U.S. SENATE,
SUBCOMMITTEE ON GLOBAL CLIMATE CHANGE AND IMPACTS,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Subcommittee met, pursuant to notice, at 2:30 p.m. in room SD–562, Dirksen Senate Office Building, Hon. David Vitter, Chairman of the Subcommittee, presiding.

OPENING STATEMENT OF HON. DAVID VITTER, U.S. SENATOR FROM LOUISIANA

Senator VITTER. This is the Subcommittee on Global Climate Change and Impacts of the Senate Commerce Committee, and our hearing today is on the projected and past effects of climate change, a focus on marine and terrestrial systems.

Thank you all for being here. Today, we'll have a hearing on just that, the projected and past effects of climate change, with a particular focus on marine and land systems.

It's clear that we are experiencing a warming trend. Many scientists say that temperatures we're seeing right now are not outside of historical ranges experienced on Earth; however, if temperatures continue to increase, we would be entering uncharted territory.

Similarly, carbon dioxide concentrations in both our atmosphere and oceans are at levels never seen before. And while I enjoy forging new frontiers in many areas, this is not one any of us are excited to do.

So, this hearing will concentrate on the realized historical and also future predicted impacts of climate change, specifically on the health of our oceans, humans, plants and animals, and other Earth systems.

I'm very interested in examining, through this hearing, how much we can ascertain from historical climatic variation and apply this knowledge to current and future changes and conditions. For once, we're not here to argue about the causes of observed warming trends or whether mandatory or market-based incentives are the best solution to reducing greenhouse gas emissions. Rather, we all agree that clearly understanding the potential changes we face in our environment as a result of this current cycle is an important task.

We've seen predictions that our seas will rise 30 feet, and other extraordinary estimates. Certainly, I hope those won't come true. If so, I imagine many of us will have to migrate to higher ground in Alaska, maybe even run against Ted Stevens. I don't look forward to that. I know what the outcome would be.

In addition, the State of Louisiana has many low-lying coastal areas, as many in the Nation discovered after Hurricanes Katrina and Rita. The impressive work of LSU's Spatial Reference Center and the Center for GeoInformatics and the National Geodetic Survey have been very helpful in providing data we need in our part of the world, in terms of that situation in south Louisiana.

So, we're facing many of these challenges at home. The land is sinking, levees are settling. We lose a football field of wetlands every 38 minutes. The Corps of Engineers is currently rebuilding our flood and hurricane protection systems without the design flaws of the past, but the issue of net sea-level rise is very important as we do that work, as well.

Sea-level rise is just one component of the hearing today. The State of Louisiana is the largest producer of fisheries in the lower 48, and we need to gain a better understanding of how ocean changes could affect our fishermen and the growing demand for wild, domestic seafood.

We'll also discuss other potential changes related to our polar and temperate glaciers, impacts on plants and animals, and, of course, the important issue of human health.

I want to commend to my colleagues that we share the common goal of ensuring the best science and understanding of all of these potential future changes.

As CEQ Chair Jim Connaughton testified at our last hearing, the U.S. is dedicating more resources to climate change science and technology than any other country, probably more than all other countries combined. We're seeing reductions in our emissions intensity now, and we must continue these efforts to meet national goals.

In closing, I want to point out that we have witnesses that have traveled from Paris and Fairbanks to be with us today. And, while I appreciate all of you being here today, I want to extend a special thanks to Dr. Akasofu and Dr. Reiter for your efforts to be with us. And I look forward to everyone's testimony.

With that, we'll turn to the full Committee Chairman, Senator Stevens.

STATEMENT OF HON. TED STEVENS, U.S. SENATOR FROM ALASKA

The CHAIRMAN. Well, thank you very much, Senator Vitter, for conducting this hearing.

At my suggestion, the full Committee created this new subcommittee to deal specifically with global climate change. And it's imperative that the decisionmakers in all our governments and industry have the best possible science to rely upon as we deal with the problems of global climate change.

There is a great deal of uncertainty, as we all know, about the causes, but I don't think there's much, really, doubt that there are changes taking place, and in particular in Alaska and the Arctic.

We have faced severe coastal erosion. We have faced polar glacier recession. We have had melting permafrost, migration of species, all sorts of problems regarding our forests, and increased risks of fires in Alaska. And our native villages have faced the problems of changes that are much greater than taking place anywhere else in the United States.

We think that if we can understand and, really, watch what's going on in Alaska, that the rest of the country will learn from it. And I hope that this hearing will demonstrate that.

It is critical that we examine the problems of Alaska on the basis of sound science, and that's why I'm delighted that there are some familiar faces here today, for me. Dr. Bob Corell is Chair of the Arctic Climate Impact Assessment Team, and he's done a great deal of research. We'll learn more about that today. And my long-time friend and advisor, Dr. Syun Akasofu, who directs our International Arctic Research Center in Fairbanks. He has, as you said, flown a long way, and I think it's about the third time he's come down this year, at our request, to appear in various ways. He earned his doctorate in studying the composition of the aurora borealis—"northern lights," to most people—and he's devoted 20 years now to studying the climate of our area. So, I know of no one in the world that I would rely on more than Syun, who has, I think, demonstrated his objectivity and his honesty, in terms of dealing with these issues.

So, again, I think that this is a very timely hearing. I wish the whole Senate was here to listen to these people, because these are the people that can give us the information now that we ought to listen to as we try to consider some of the suggestions that are being made concerning what the Federal Government could do—should do concerning global climate change.

Thank you very much.

Senator VITTER. Thank you, Mr. Chairman.

And we also have our Ranking Member, Senator Lautenberg.

Thank you for being here, Senator. And if you have any opening statement, please feel free to make it.

STATEMENT OF HON. FRANK R. LAUTENBERG, U.S. SENATOR FROM NEW JERSEY

Senator LAUTENBERG. Thanks, Mr. Chairman. I'm pleased to be here. And I'm pleased, particularly, that our Chairman of the whole Committee is with us.

We have, Mr. Chairman, a vote that's started. And I don't know what you'd like to schedule. Should we—I'll make my statement, and then shall we adjourn for a few minutes to carry on with our business? I'm——

Senator VITTER. Why don't we do just that, if it's——

Senator LAUTENBERG. Yes.

Senator VITTER.—agreeable to you.

Senator LAUTENBERG. That'd be perfect.

And one of the reasons that I'm pleased to share this platform today with each of you is the fact that you, in Louisiana and Alaska and New Jersey, are all threatened by these climate changes that we see and that we worry about, the sea-level rise and Atlantic storms, the increased air pollution, harm to our fisheries. But

we're also affected by things that happen beyond our shores. We'll be harmed by the impacts of global warming that occur across the oceans or on—even on the other side of the world.

Now, if the Greenland ice sheet melts into the sea, we'll be affected. If the glaciers of Central Asia disappear, taking water used for drinking and irrigation for more than a billion people with them, we will be affected. If the sea rises and washes over homes in Bangladesh, we will be affected. And if a range of plant and animal species go extinct, from frogs to sea coral to polar bears, we, all of us, will be affected.

Thousands of scientists around the world have identified potential impacts of global warming, and many of their dire predictions are already coming true; in some cases, at a rate far faster than forecasted. The indicators include increased hurricane intensity, the retreat of glaciers, loss of sea ice, and our oceans are becoming more acidic. There is no dispute that these changes are occurring. Senator Stevens said it very clearly, and there is broad scientific consensus, that the global warming that we are experiencing is mostly due to human activity, not the result of natural climate cycles.

The most common argument heard from those who oppose prompt action to address global warming is that we don't want to wreck our economy until we're absolutely sure that the threat is real. Well, there are two fallacies to this argument. First, reducing global warming will not wreck our economy. In recent years, some companies have reduced greenhouse gases and have actually found that they've saved money. Second, we can't afford to delay taking action until every doubter is convinced. Once greenhouse gases enter our atmosphere, they're going to remain for a long time, and we can't continue to race toward catastrophe, hoping that we can throw the car in reverse at the last minute. We've got to slow it down now.

We've heard these doubters before. Every time a meaningful protection of our environment or public health has been proposed, they raise reasons as to why we shouldn't be concerned about it now. The tobacco industry successfully fought efforts to curtail its deadly products for decades, based on the claim, "We just didn't know enough." But we did know enough to justify taking action.

In 1994, when President Clinton proposed stronger protections from air pollution, industry-funded think tanks argued that our economy would be ruined and that barbecues and fireworks on the 4th of July would be barred. But after President Clinton strengthened air-quality standards, our economy did thrive, and fireworks and barbecues continued.

Now, we know that global warming is occurring. We also know it will continue to increase even if we act quickly to flatten and then reduce our greenhouse gas emissions. We know that the impacts of this warming are already being observed, and that it will continue and quicken, particularly if we take no action to reverse our current course.

So, our country's got to act. And this doesn't mean that when we act, that we'll see an immediate result. But at some point a beginning has to be made, and failure to do so could be our greatest failure as a nation and as human beings.

Now, I'm pleased that we have two panels of witnesses today before us. I'm particularly interested in the views of Dr. Corell, whose ideas on this matter are well respected, as are others in the field of climate science.

Mr. Chairman, I went down to the South Pole a few years. I wanted to see what the National Science Foundation was doing. And it seemed to me, at night, that you could almost hear the glaciers groaning as there were climate shifts and as the temperatures changed. And 70 percent of the world's fresh water was stored in those—in that ice. Much of that ice has disappeared, and much more of it will disappear.

And so, once again, Mr. Chairman, I thank you for doing this. I look forward to hearing from our witnesses, and sorry that we have to delay them, but we'll be back. It's been said before.

Senator VITTER. Thank you, Senator.

And right now we'll take a very brief recess to vote on the Senate floor, and we'll all return absolutely as quickly as possible. I apologize for the delay.

[Recess.]

Senator VITTER. We'll reconvene the hearing. Thanks to everyone, particularly our witnesses, for their patience.

We'll start with Panel I, comprised of two individuals. First, Dr. Steve Murawski, Director of Scientific Programs and Chief Science Advisor for the National Marine Fisheries Service and Ecosystem Goal Team Lead with the National Oceanic and Atmospheric Administration, and then he'll be followed by Dr. Thomas Armstrong, Program Coordinator of the Earth Surface Dynamics Program with the U.S. Geological Survey.

Thank you both for being here. And, Dr. Murawski, please begin.

STATEMENT OF STEVEN A. MURAWSKI, PH.D., DIRECTOR OF SCIENTIFIC PROGRAMS/CHIEF SCIENCE ADVISOR, NATIONAL MARINE FISHERIES SERVICE AND ECOSYSTEM GOAL TEAM LEAD, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, DEPARTMENT OF COMMERCE

Dr. MURAWSKI. Good afternoon, Chairman Vitter and Chairman Stevens. Thanks for the opportunity to testify.

Among NOAA's diverse missions, our tasks include understanding and predicting changes in the Earth's environment and acting as the Nation's principal steward of coastal and marine resources critical to our Nation's economic, social, and environmental needs.

Climate change is only one of a complex set of interacting factors that simultaneously influence the marine ecosystems. It is challenging, but vital, for us to isolate the influences of individual factors, such as natural and anthropogenic climate cycles and other influences, such as pollution, land development, fishing pressures, and others on ecosystems.

In order to manage such a complex set of human activities, NOAA is committed to an ecosystem approach that addresses the many simultaneous pressures affecting resources, including the effects of climate change.

Because changing climate is one of the significant long-term influences on marine species, we must meet this challenge head-on.

Climate-related issues are of particular concern for marine ecosystems that include the effects of long-term rising sea levels, increasing acidification of the world's oceans, bleaching of shallow-water coral reefs, loss of sea ice, and rising water temperatures. All of these factors have been documented as influencing marine ecosystems, and all are cause for concern. As Winston Churchill said, "The farther backward you can look, the farther forward you're likely to see."

Paleoclimate and paleoecological indicators provide perspective on the scale of recent observed changes in marine ecosystems. Over hundreds of thousands of years, numerous ice ages and warming events have occurred, and populations have responded by changing growth patterns, abundance, and geographic location.

Over the last 10,000 years since the last ice age, there were slightly warmer than average conditions during 1200 to 1400 A.D., slightly cooler conditions from 15- to 1800 A.D.—that is the Little Ice Age—and an increase in the last centuries to temperatures that are the warmest in the last millennium.

Companion biological records show that, as compared to the preceding 1,000 years, organisms and the ecosystems are now exhibiting unusual patterns of growth, abundance, distribution, and other characteristics.

Recent changes in the Earth's climate are having observable impacts on marine ecosystems and the human communities that depend on them. Rising sea levels alter ecosystems and habitat in coastal regions. The coastlines of our Atlantic and Gulf States, as well as portions of Alaska and the Pacific Islands are especially vulnerable to long-term sea-level rise. For example, coastal Louisiana is projected to have sea-level rise 3 to 4 feet over the next century. Factors contributing to sea-level rise in coastal Louisiana are complex and multifaceted. Rising sea levels in coastal Louisiana are having effects on coastal marshes that are important to nursery areas for Gulf Coast fisheries.

The oceans are the largest reservoir of carbon dioxide. Estimates are that by the middle of this century, atmospheric carbon dioxide levels will increase, resulting in a decrease in the surface water pH by approximately 0.4 pH units.

As the oceans become more acidic, more species of marine plankton will have a reduced ability to produce protective calcium carbonate shells. These plankton species are the base of the marine food web, and shifts in the base can have cascading consequences through trophic levels. The loss of calcium carbonate will also have negative impacts on the world's coral reefs, which are areas of the highest biodiversity in the ocean. Coral reefs are also extremely vulnerable to sea surface temperatures. Rising global temperatures over the past 30 years have been accompanied by an increase in the extent and frequency of coral bleaching in many tropical areas of the world. September of 2005 was, by far, the warmest in the eastern Caribbean in the entire 100-year record that we have. Many of these areas experienced over 90 percent of corals bleached, and 30 percent of the corals have died in some of these areas. This loss is significant, as coral reef ecosystems are among the most diverse and biologically complex areas in the oceans.

The loss of sea ice has been documented in both the Arctic and the Antarctic. The amount and duration of ice cover in the southeast Bering Sea has decreased substantially since the early 1970s as the southeast Bering Sea has warmed 2 to 3 degrees Centigrade in the past 10 years. These changes have had substantial biological impacts on the distribution and abundance of many commercial finfish and shellfish species. This means that the resource base supporting individual communities has been displaced, affecting the economics of fisheries and the communities. Other changes in the food web of the Bering Sea have occurred, affecting marine mammals and subsistence hunting for them.

Temperatures in the South Shetland Islands in Antarctica have warmed by over 4 degrees Centigrade since the 1940s, and the extent of ice around Antarctica has declined appreciably. The density of krill, a central link in the Antarctic food web, has decreased by more than 90 percent in the region since 1976. Declines in krill have been associated with decreasing populations of penguins, seals, and other marine life.

In temperate regions, many marine fish and shellfish species have been observed to shift their distributions northward in response to warmer waters.

This is just a sample from the growing body of evidence linking climate change to marine ecosystem function. It is our challenge to understand these linkages both to better predict their effects and to identify the conservation and management policies in the face of changing climate that may help to mitigate their effects.

Improving the predictability of ocean responses to a changing climate will require improvements in ocean observing, research, and modeling. A large broadscale and robust system for observing and measuring oceanographic climate and economic conditions is essential to better understanding climate change effects and ecosystem effects.

To provide such a comprehensive set of measurements, the Administration and NOAA have supported the development of the U.S. Integrated Ocean Observing System, or IOOS. The full development of IOOS is a high priority for improving our understanding of climate effects on marine ecosystems.

And, last, the President's FY 2007 budget request restores significant cuts made by Congress in NOAA's climate program in 2006. This funding is critical to NOAA's ability to understand and study climate change, including the impacts of climate on ecosystems. And we urge the Committee to support NOAA's FY 2007 budget request.

Thank you, Mr. Chairman. I'd be happy to answer questions.

[The prepared statement of Dr. Murawski follows:]

PREPARED STATEMENT OF STEVEN A. MURAWSKI, PH.D., DIRECTOR OF SCIENTIFIC PROGRAMS/CHIEF SCIENCE ADVISOR, NATIONAL MARINE FISHERIES SERVICE AND ECOSYSTEM GOAL TEAM LEAD, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, DEPARTMENT OF COMMERCE

Introduction

Good afternoon, Mr. Chairman and Members of the Committee. My name is Steven Murawski, and I am the Director of Scientific Programs and Chief Science Advisor at the National Marine Fisheries Service (NMFS), within the National Oceanic and Atmospheric Administration (NOAA). I also serve as leader of NOAA's Eco-

system Goal Team, which integrates the Agency's many ecological activities across its various offices. Thank you for inviting NOAA to discuss projected and past effects of climate change with a focus on marine and terrestrial ecosystems. Among NOAA's diverse missions, our tasks include understanding and predicting changes in the Earth's environment and acting as the Nation's principal steward of coastal and marine resources critical to our Nation's economic, social and environmental needs.

Today I will focus my remarks on how changes in climate affect marine ecosystems, particularly as they relate to NOAA's stewardship responsibilities. NOAA's work on climate change and ecosystems relevant to this hearing includes observations of the physical environment and biota, research to understand the changes in the environment and the broader ecosystem, and incorporating projected impacts of climate change into NOAA's conservation and management programs for living marine resources and ecosystems. Climate change is only one of a complex set of factors that influence marine ecosystems. It can be difficult to separate the influence of natural climate cycles, recent climate change, and other factors such as overfishing, air pollution such as sulfates, agricultural run-off, land use changes resulting from land fills, drainage practices, uses of pesticides and fertilizers, development, recreational facilities and practices, inadequate storm water management, and sewage treatment. NOAA is committed to an ecosystem approach to resource management that addresses the many simultaneous pressures affecting ecosystems.

This Administration recognizes climate change as a complex and important issue and acknowledges human activities are contributing to recent observed changes in the climate system. However, scientific uncertainties still remain, including how much of the observed warming is due to human activities and how large and fast future changes will be. In 2002, the Administration created the Climate Change Science Program (CCSP; the Federal interagency program focused on climate change research) to ensure the Federal Government's efforts and resources are used to obtain the best possible scientific knowledge as the foundation to address challenging climate change questions and support decisionmaking. There is much important research yet to be done and CCSP—whose leadership resides in NOAA—is seeking to increase our understanding of climate change. Within CCSP there is an Ecosystem Interagency Working Group which is currently examining a variety of topics relevant to today's hearing, including: (1) the use of integrated modeling systems, observations, and process studies to project the effects of climate variability and change on near-coastal and marine ecosystems and communities; (2) combined effects of changes in land use and climate on non-point sources of pollution entering estuaries; and (3) a long-term study of the western U.S. mountains and the relationship of observed sudden ecosystem changes to changes in climate conditions.

The Climate Change Science Program is a coordinated effort across 13 agencies (U.S. Agency for International Development; Department of Agriculture; Department of Commerce, National Oceanic and Atmospheric Administration and National Institute of Standards and Technology; Department of Defense; Department of Energy; Department of Health and Human Services, National Institutes of Health; Department of State; Department of Transportation; Department of the Interior, U.S. Geological Survey; Environmental Protection Agency; National Aeronautics and Space Administration; National Science Foundation; and the Smithsonian Institution), 12 of which fund CCSP research. Funding for NOAA's CCSP initiatives are included within the NOAA Climate Program. The fiscal 2007 President's budget request for NOAA includes spending for CCSP near-term research focus areas, including integrating new remote-sensing observations with expanded observations to build the next generation of climate prediction capabilities; development of an integrated Earth system analysis capability; integrating of water cycle observations, research and modeling; using global LANDSAT data to answer critical climate questions; an integrated North American Carbon Program; understanding the impacts of climate variability and change on ecosystem productivity and biodiversity; coping with drought through research and regional Partnerships; the International Polar Year; and an Integrated Ocean Observing System. The President's budget restores cuts made by Congress to NOAA's Climate Program in 2006, particularly in the area of Research Supercomputing, critical to NOAA's ability to reduce some of the highest uncertainties in understanding impacts of climate variability and change. We urge the Committee to support the FY 2007 President's budget request for NOAA.

In my testimony today I will: (a) provide information on NOAA's contributions relevant to climate change science and links to effects on marine ecosystems, (b) detail the importance of understanding climate-ecosystem links both for the affected marine areas and the human communities dependent upon them, (c) briefly describe some paleontological observations of how ecosystems have changed in response to

climate variations in the past, and (d) review some contemporary observed changes in marine ecosystems thought to be related to changes in the Earth's climate and issues surrounding them. Finally, I will outline some of the scientific challenges and needs for improving science to better define ecosystem impacts and inform conservation and management strategies for living marine resources taking into account climate impacts.

NOAA's Roles in Climate and Ecosystem Sciences

Within the climate science community, NOAA is a recognized leader both nationally and internationally. Our scientists actively participate in many important national and international climate working groups and assessment activities. One of NOAA's mission goals is to "understand climate variability and change to enhance society's ability to plan and respond." NOAA is the only Federal agency that provides operational climate forecasts and information services (nationally and internationally). NOAA is the leader in implementing the Global Ocean Observing System (NOAA contributes 51 percent of the world-wide observations to GOOS, not including satellite observations). NOAA also provides scientific leadership for the Intergovernmental Panel for Climate Change Working Group I and CCSP. To better serve the Nation, NOAA recently created a Climate Program Office (CPO) to provide enhanced services and information for better management of climate sensitive sectors, such as energy, agriculture, water, and living marine resources, through observations, analyses and predictions, and sustained user interaction. Services include assessments and predictions of climate change and variability on timescales ranging from weeks to decades.

Within the ecosystem community, NOAA's ecosystem researchers have been at the forefront of establishing links between ocean variability and impacts on marine ecosystems. NOAA has funded some research programs specifically dedicated to evaluating impacts of changes in the physical environment on marine resources. These include a program jointly undertaken with the National Science Foundation called GLOBEC (Global Ocean Ecosystem Dynamics), which just last week co-hosted a symposium on "Climate variability and ecosystem impacts on the North Pacific" with PICES (the North Pacific Marine Science Organization of which the U.S. is also a member). An exclusively NOAA program called NPCREP (North Pacific Climate Regimes and Ecosystem Productivity) seeks to improve climate-ecosystem science in the Alaskan Large Marine Ecosystem complex. Even more information on the impacts of climate on marine ecosystems is derived from NOAA's many observing programs established to aid in the management of fisheries, protected species, marine sanctuaries, corals and other specific Agency mandates.

These data, primarily collected in support of NOAA's ecosystem stewardship authorities, provide a wealth of information for interpreting climate impacts when combined with NOAA's climate, oceanographic and weather information. Results of these analyses have been widely disseminated and NOAA's contributions to the emerging science of ecosystem impacts of climate change have been significant. However, a greater understanding of the full range of climate induced impacts on ecosystems will require us to increase our observation of ecosystems in relation to variable climate forcing and focus our research on the mechanisms through which ecosystems are affected. In this way we can develop quantitative assessments and projections of climate's ecological impacts, including impacts on the resources on which human communities rely.

Why are Links between Climate and Marine Ecosystems So Important?

Irrespective of the ultimate causality, changes in the world's climate has resulted in changes in marine ecosystems, on several different time scales, affecting the abundance, distribution and feeding relationships among components of many marine communities [1, 2, 3, 4, 5, 6] While we are still working toward a complete understanding of the causes of the observed phenomena, recent projections indicate that a number of climate change scenarios have the potential to affect marine ecosystems in even more fundamental ways. These changes are related both to long-term trends in the ocean environment and to the cyclic variation in ocean conditions observed in many areas. These changes are important in their own right, but even more so because of the dependence of many of our coastal communities on living marine resources—for food, recreation, and cultural fulfillment. Over half of the U.S. population now lives within 100 miles of the coast, and this proportion is increasing dramatically. Our $60 billion per year seafood industry, marine tourism industries, recreational activities, and the very existence of some communities may be dependent on changing ocean conditions affecting marine ecosystems.

Changing climate is one of the most significant long-term influences on the structure and function of marine ecosystems and must therefore be accounted for in

NOAA's management and stewardship goals to ensure healthy and productive ocean environments. Changes and variations in climate may directly or indirectly impact marine ecosystems. This includes changes and variations of sea surface temperature, ocean heat content, sea level, sea ice extent, freshwater inflow and salinity, oceanic circulation and currents, pH, and carbon inventories. Each of these properties of the global ocean is being measured to varying degrees by NOAA. Through the continued collection of data and the implementation and integration of observing systems, we strive to create longer, more globally inclusive data records that will improve our understanding of climate change and our ability to reliably predict impacts on marine ecosystems over time scales of interest to our constituents now (e.g., 5–10 year time horizon) and in the future.

A Paleontological Perspective on the Impacts of Climate Change on Marine Ecosystems

The paleoclimate record provides a long view of how populations and entire ecosystems have responded to climate change over hundreds to thousands of years. Many sources of paleoclimate data are from biological indicators such as tree rings, corals, and fossil plankton. By comparing the time series from biological indicators with paleoclimate data from non-biological material such as ice cores, boreholes, and cave stalagmites, one can reconstruct not only how climate has changed, but also how marine and terrestrial populations have responded.

Over hundreds of thousands of years, ice ages have come and gone, and populations have responded by changing growth patterns, abundance and geographic location. Remarkably only a few documented extinctions occurred in terrestrial and marine ecosystems during ice age cycles, apart from the extinction of the Pleistocene megafauna (e.g., the woolly mammoth). Just as the changes in climate during the ice ages were large and sometimes abrupt, ecosystem changes were similarly large and abrupt. For example, at the end of the last ice age, pollen from lake sediments indicate an abrupt northward migration and establishment of the modern biomes across North America,[7] while in the adjacent oceans fossil plankton from marine sediments reveal that the region where certain plankton species were abundant also moved to higher latitudes.[8]

While these changes in the ocean environment were abrupt compared to the radiation changes that caused the ice ages, the changes were slow compared to the changes occurring in the current millennium. The end-of-the-ice-age ecosystem changes occurred over thousands of years. Over the last 10,000 years climate has remained relatively stable apart from small changes caused by the changes in seasonal solar radiation. Over the past 1,000 years, where the paleoclimate record is most complete, climate has been even more constant except for the recent trends in temperature and rainfall. The climate of the last 1,000 years can be characterized as: 1200–1400 AD—slightly warmer than average conditions; 1500–1800 AD—slightly cooler than average conditions; and 1900–2000 AD—an increase in the last centuries to temperatures that are likely to be the warmest in the last millennium.[9, 10] Companion biological records show that organisms and ecosystems are changing in growth pattern, abundance, and other characteristics in ways that are unusual compared to the preceding 1,000 years. Detailed information on terrestrial and marine ecosystem responses to past climate change is detailed on the NOAA Paleoclimatology website (*www.ncdc.noaa.gov/paleo*). One selected example relevant to marine ecosystems involves the long record of sockeye salmon populations in Alaska.

The paleoclimate record of sockeye salmon from Alaskan lakes reveals the difficult task of separating the influence of natural climate cycles, recent climate change, and fishing pressure on salmon abundance. Sockeye salmon return to lakes in Alaska to spawn, and their remains are reflected in chemical (e.g., nitrogen-15) concentrations in lake sediments, creating a 2000 year-long record of salmon abundance. Dr. Bruce Finney, from the University of Alaska, and his colleagues correlated centuries-long cycles in salmon abundance with climate variations from other paleo proxies, demonstrating the existence of natural cycles in salmon populations prior to significant human activity in the region.[11] Near the end of the record the decline due to intense fishing pressure in the last century is also evident. Finney and colleagues note that natural cycles in salmon abundance appear out of phase with the abundance of other fish species farther south in the California Current system, a pattern they also attribute to natural climate variability. In addition to fish abundance, paleo-ecological records have also been developed for plankton that form the base of the food chain. Compared to the fish proxies, the plankton records are more complete and subject to fewer uncertainties. While these records are continuously being developed, the records published so far document a clear link between climate

change and marine ecosystems. One important conclusion from this work is that marine ecosystems are sensitive to even small changes in climate.

Current and Projected Impacts of Climate Change on Marine Ecosystems and Living Marine Resources

Impacts of Sea Level Rise on Ecosystems

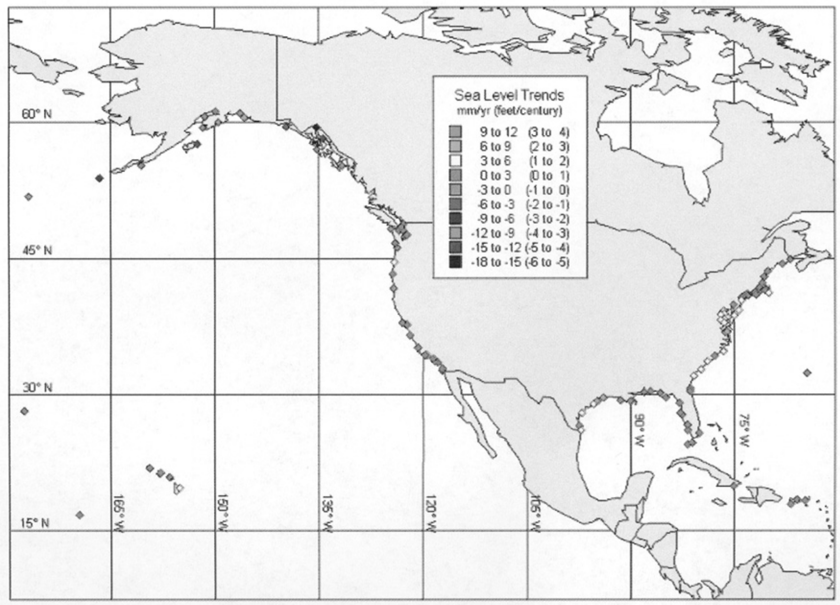
Sea level rise is projected to accelerate during the 21st century, with the most significant impacts in low-lying regions where subsidence and erosion problems already exist. Rising sea level has worldwide consequences because of its potential to alter ecosystems and habitat in coastal regions. Sea level rise and global climate change issues in the coastal zone include:

- Higher (deeper) and more frequent flooding of wetlands and adjacent shores;
- Increased flooding due to more intense storm surge from severe coastal storms;
- Increased wave energy in the nearshore area;
- Upward and land-ward migration of beaches;
- Accelerated coastal retreat and erosion;
- Saltwater intrusion into coastal freshwater aquifers;
- Damage to coastal infrastructure; and
- Broad impacts on the coastal economy.

The coastlines of our Atlantic and Gulf states, as well as portions of the Alaska coastline are especially vulnerable to long-term sea level rise. The slope of these areas is so gentle that any small rise in sea level can produce a large inland shift of shoreline.

Sea level rise threatens to alter wetland ecosystems. Sea level rise may also result in increased susceptibility to nutrient-related eutrophication, due to changes in estuarine circulation. Changes in the wetland and estuarine processes will affect resident marine organisms and the fisheries dependent upon them.

NOAA has maintained long-term continuously operating stations of the National Water Level Observation Network (NWLON), and has recently documented the relative sea level trends at all of the longest-term stations (1854–present). The map below (also available at *http://tidesandcurrents.noaa.gov/sltrends/slrmap.html*) shows sea level trends for the United States for those locations where tide stations exist. This map provides an indication of the differing rates of relative sea level rise (vertical land and sea level motion combined) around the United States. There is a general scientific agreement that sea level rise is occurring at a global average rate of 2 mm per year. Referring to the map the mid-Atlantic and Gulf Coast are experiencing 3–5 mm and 5–15 mm per year rise in sea level, respectively.



One area particularly vulnerable to sea level rise is coastal Louisiana. The graphic above illustrates that these areas are projected to have sea levels rise *3–4 feet* over the next century. Factors contributing to sea level rise in coastal Louisiana are complex and multifaceted, including land subsidence due to petroleum extraction, declining sediment loads deposited from rivers into the marshes, land use practices exacerbating wetlands loss, and rising sea levels due to global climate change and other factors. Whatever the causes, a 3–4 foot rise in sea level in coastal Louisiana will have profound effects on marine resources, since coastal marshes there are important nursery areas for most of the valuable living resources (e.g., shrimp, oysters, many finfish species) in the Gulf of Mexico. In addition, loss of Louisiana's coastal marshes to sea level rise makes coastal communities much more vulnerable to recurring storm events.

The Northwestern Hawaiian Islands (NWHI) are of particular concern with respect to sea level rise. The NWHI have high conservation value due to their concentration of endemic, endangered and threatened species, and large numbers of nesting seabirds. Most of these islands are low-lying and therefore potentially vulnerable to increases in global average sea level. The potential for NWHI habitat loss was recently assessed by the NMFS Pacific Islands Fisheries Science Center, by creating topographic models of several islands and atolls in the NWHI and evaluating the potential effects of sea-level rise by 2100 under a range of basic passive flooding scenarios. Projected terrestrial habitat loss varied greatly among islands: 3 percent to 65 percent under a median scenario (48-cm rise), and 5 percent to 75 percent under the maximum scenario (88-cm rise). Spring tides may repeatedly inundate all land below 89 cm (median scenario) and 129 cm (maximum scenario) in elevation. Sea level is expected to continue increasing after 2100, which would have greater impact on atolls such as French Frigate Shoals and Pearl and Hermes Reef, where virtually all land is less than 2 m above sea level. Higher islands such as Lisianski, Laysan, Necker, and Nihoa may provide longer-term refuges for species. The effects of habitat loss on NWHI biota are difficult to predict, but may be greatest for endangered Hawaiian monk seals, threatened Hawaiian green sea turtles, and the endangered Laysan finch at Pearl and Hermes Reef.

Ocean Acidification

The oceans are the largest natural long-term reservoir for carbon dioxide, absorbing approximately one-third of the carbon dioxide added to the atmosphere by human activities each year. Over the past 200 years the oceans have absorbed 525 billion tons of carbon dioxide from the atmosphere, or nearly half of the fossil fuel carbon emissions over this period. Over the next millennium, the global oceans are

expected to absorb approximately 90 percent of the carbon dioxide emitted to the atmosphere.[12]

For over 20 years, NOAA has participated in decadal surveys of the world oceans, documenting the ocean's response to increasing amounts of carbon dioxide being emitted to the atmosphere by human activities. These surveys confirm that oceans are absorbing increasing amounts of carbon dioxide. Estimates of future atmospheric and oceanic carbon dioxide concentrations, based on the Intergovernmental Panel on Climate Change emission scenarios and general circulation models, indicate that by the middle of this century atmospheric carbon dioxide levels could reach more than 500 parts per million (ppm), and near the end of the century they could be over 800 ppm. This would result in a surface water pH decrease of approximately 0.4 pH units as the ocean becomes more acidic, and the carbonate ion concentration would decrease almost 50 percent by the end of the century. To put this in historical perspective, this surface ocean pH decrease would be lower than it has been for more than 20 million years.[13]

Recent studies indicate that such changes in water chemistry, or ocean acidification as the phenomenon is called, would have effects on marine life, such as corals and plankton.[13, 14] The carbonate chemistry of seawater has a direct impact on the dissolution rates of calcifying organisms (coral reefs and marine plankton). As the pH of the oceans decreases and becomes more acidic, some species of marine algae and plankton will have a reduced ability to produce protective calcium carbonate shells. This makes it more difficult for organisms that utilize calcium carbonate in their skeletons or shells to build and maintain their structures. These organisms form the foundation of the food chain, upon which other marine organisms feed. Decreased calcification may also compromise the fitness or success of these organisms and could shift the competitive advantage toward organisms not dependent on calcium carbonate. Carbonate skeletal structures are likely to be weaker and more susceptible to dissolution and erosion. There is paleooceangraphic evidence that during the last high CO_2 regime (55 million years ago) increased ocean acidification was associated with mass extinctions of phytoplankton species, followed by a recovery period of about 80,000 years.[15] Because of the importance of phytoplankton to marine food webs, biodiversity and productivity of the oceans may be altered[14], which may result in adverse impacts on fishing, tourism, and other economies that rely on the continued health of our oceans.

Recent findings indicate that such conditions could develop within decades at high latitudes.[14] This will likely have impacts on high latitude ecosystems because pteropods, a shelled, swimming mollusk, is a significant prey item for fish in these regions. It is important to gain a better understanding of how ocean chemistry and biology will respond to higher carbon dioxide conditions so that predictive models of the processes and their impacts on marine ecosystems can be developed.

Coral Bleaching Events

Coral reef ecosystems are among the most diverse and biologically complex ecosystems on Earth and provide resources and services worth billions of dollars each year to the United States economy and economies worldwide. Coral reefs support more species per unit area than any other marine environment, including about 4,000 species of fish, 800 species of hard coral and thousands of other species. Approximately half of all federally-managed fish species depend on coral reefs and related habitats for a portion of their life cycles. The National Marine Fisheries Service estimates the annual commercial value of U.S. fisheries from coral reefs is over $100 million. Local economies also receive billions of dollars from visitors to reefs through diving tours, recreational fishing trips, hotels, restaurants, and other businesses based near reef ecosystems. In the Florida Keys, for example, coral reefs attract more than $1.2 billion annually from tourism. In addition, coral reef structures buffer shorelines against waves, storms and floods, helping to prevent loss of life, property damage and erosion.

Coral reefs are extremely vulnerable to increased sea surface temperatures. As global temperatures have risen over the past 30 years, there has been a corresponding increase in the extent and frequency of extremely high sea surface temperatures and coral bleaching events in many tropical regions.[4, 16]

Coral bleaching is a response of corals to unusual levels of stress primarily thought to be associated with light and ocean temperature extremes. Bleaching occurs when corals expel their symbiotic algae and lose their algal pigment. Loss of the symbiotic algae leaves the coral tissue pale to clear and, in extreme cases, causes a bleached appearance. Corals often recover from mild bleaching. However, if the stress is prolonged and/or intense, the corals may die or weaken, causing them to be more susceptible to disease and other stressors.

Coral bleaching has occurred in both small localized events and at large scales. Although many stressors can cause bleaching, mass bleaching events have almost exclusively been linked to unusually high ocean temperatures. There is still much that we do not know about the impacts of bleaching-associated mass coral mortality on: (1) the function of coral reef ecosystems; (2) the associated fisheries; and (3) the value (loss) to recreation and tourism industries.

Through satellite and *in situ* monitoring of thermal stress, NOAA tracks the conditions that may lead to coral bleaching. When the data show that conditions are conducive to bleaching, NOAA provides watches, warnings, and alerts to users throughout the globe through NOAA's Coral Reef Watch project and Integrated Coral Observing Network. Coral bleaching alerts allow managers and scientists to deploy monitoring efforts which can document the severity and impacts of the bleaching to improve our understanding of the causes and consequences of coral bleaching.

Large scale or mass bleaching events were first documented in the eastern Pacific in the early 1980s in association with the El Niño Southern Oscillation.[16] In 1997–1998, coral bleaching became a global problem when a strong El Niño (period of warmer than average water temperature), followed by a La Niña (period of colder than average water temperature) caused unprecedented coral bleaching and mortality world-wide.[17]

However, coral bleaching events are not only tied to the El Niño/La Niña phenomena. In 2005, a year lacking El Niño or La Niña climate patterns, unusually warm temperatures were recorded in the tropical North Atlantic, Caribbean, and Gulf of Mexico. Corals in the Caribbean region experienced temperatures in 2005 that greatly exceeded any of the previous 20 years. While the thermal stress in the Caribbean has increased over the last 20 years, 2005 was a major anomaly from the upward trend in temperatures there. As a result of NOAA satellite and *in situ* monitoring, we were able to alert managers and scientists to this temperature anomaly. The unusually warm temperatures gave rise to the most intense coral bleaching event ever observed in the Caribbean. NOAA is working with local partners in Florida, Puerto Rico and the U.S. Virgin Islands to better assess the impacts from the 2005 bleaching event. It is clear that mass bleaching is a serious concern to the communities that depend upon these resources.

Preliminary analyses by NOAA show that the cumulative thermal stress for 2005 was 50 percent larger than the cumulative stress of the prior 20 years combined.[18] September 2005 was by far the warmest September in the Eastern Caribbean in the entire 100-year record. Many areas, including the U.S. Virgin Islands, averaged over 90 percent of their corals bleached and some have already lost 30 percent of these corals due to direct thermal stress or subsequent disease. NOAA is currently analyzing the impact of this bleaching event on already vulnerable elkhorn and staghorn coral species. These two species have been proposed for listing as "threatened" under the Endangered Species Act.

NOAA and the Department of the Interior (DOI) are leading the interagency effort of the U.S. Coral Reef Task Force to respond to and assess the massive coral bleaching event in the Caribbean region in 2005. This effort has engaged many government and non-government partners from across the region to assess the impacts of the massive event and make recommendations on how to prepare for and address future events. For example, NOAA, DOI, and the National Aeronautics and Space Administration (NASA) conducted missions in October and December 2005 to examine the extent of bleaching and recovery/mortality of corals within the Buck Island Reef National Monument, as well as obtain aerial and hyperspectral imagery to quantify the extent of bleaching within St. Croix, St. John, and southwestern Puerto Rico. Initial findings indicate that in many areas, including the U.S. Virgin Islands, over 90 percent of coral cover had bleached. While some recovery had occurred by December, hardest hit areas have already had over 30 percent of their coral die. Further analyses are currently underway.

Impacts of Climate on Fisheries and Protected Resources

NOAA has stewardship responsibilities for coastal and living marine resources from over 90 Acts of Congress. Resources managed under these authorities are extremely valuable to the country, with fisheries alone contributing over $60 billion a year and 520,000 jobs to the U.S. economy. Interannual climate variability (e.g., El Niño, La Niña) and trends (e.g. global warming) can cause profound geographic shifts in marine ecosystems and are of great consequence to fishery-dependent communities. Climate variability/change impacts environmental conditions on multiple time scales, ranging from interannual to decadal; since Earth's temperature is warming on a global scale, it is important to assess the environmental impacts on large marine ecosystems.

In the past several decades, there have been significant changes in the distribution, growth, and abundance of living marine resources resulting from changes in ocean temperatures and related ocean conditions. These changes have occurred in polar regions, in temperate waters, and in the tropics. These changes have altered the productivity and structure of marine food webs and change the flow of goods and services to coastal communities. Below are cited some specific examples of ecosystems changes documented by NOAA that are likely linked to climate variations.

Polar Regions: Loss of sea ice at high latitudes has been documented in a number of recent scientific articles and other forums. Until recently, the northern Bering Sea ecosystem had extensive seasonal sea ice cover and high water column and sediment carbon production. Recently, NOAA researchers and other colleagues have demonstrated that these ecosystems are shifting away from these characteristics.[2, 19] The amount and duration of ice coverage in the southeast Bering Sea has decreased substantially since the early 1970s. In addition, the southeast Bering Sea has warmed 2–3°C over the past 10 years. Recent work has documented differences in ice coverage and thickness as far north as St. Lawrence Island in the northern Bering Sea. These changes have substantial impacts to both arctic and subarctic marine species in the area. For example, Greenland turbot, a flatfish that prefers cold temperatures, has shown a steady decrease in abundance since the mid-1970s. During this same time period, abundance of walleye pollock, which prefers warmer waters, has increased dramatically, with the present landings valued at $295 million per year. Bering Sea snow crab distribution has shifted northward, and pollock distribution in the Bering Sea may soon follow, affecting ecosystem interactions, fishery assessment surveys and the economics of the fishing fleet which have to travel farther and spend more days at sea to find and capture the same number of fish. In addition, juvenile pollock act as forage fish in this ecosystem and changes in their abundance, size, or distribution has the potential to affect marine mammals.

Changes in the Bering Sea marine mammals have also been observed. Gray whales have shifted their distributions northward, apparently in response to decreases in sea ice and declines in their preferred prey on the ocean floor.[20] In addition, ice-dependent seals (ring, spotted, bearded, and ribbon seals) require ice for parts of their life history (molting and pupping) and there is concern that these animals are being forced away from suitable feeding grounds as the ice retreats.[21] Similar concerns have been expressed regarding polar bear and walrus populations in Alaska.[21, 22] These changes to the ecosystem have clear implications for subsistence harvests in Alaskan native communities.

In addition to the effects of climate variability and change on the distribution and abundance of commercially important species of fish and shellfish, as well as marine mammal species important to subsistence hunters, the reduction in the extent and duration of sea ice in the Bering and Chukchi Seas in recent years has led to serious erosion problems for several remote villages and towns, including Barrow, Pt. Lay, Wales, and particularly in the village of Shishmaref. In these villages, traditionally the sea ice would buffer the impacts of storm driven waves during the winter and spring. With less sea ice, wave action is causing serious erosion problems and threatening buildings and roads. To better predict the likely rate at which erosion will impact this area, requires better information on trends in sea level height, extent and duration of sea ice, and storm frequency.

Decreases in sea ice appear to be affecting other ecosystems as well. The annual air temperature near the South Shetland Islands, Antarctica has warmed by over 4°C since the 1940s[23] and ice extent around areas of Antarctica monitored by NOAA has declined appreciably.[24] Air temperatures at Palmer station are closely correlated with the annual amount of ice cover. While air temperatures in the Shetlands have increased, the density of krill, a shrimp-like organism that is the central link in the Antarctic food web has decreased by more than 90 percent in the region since 1976.[25] Warming of Antarctic waters and loss of ice affect predator (seals, penguins, whales, etc.) and krill populations in the Southern Ocean in several ways. Krill are a keystone species in the Antarctic because so many species (fish, seals, penguins, sea birds, whales) feed upon them. Declines in krill populations will negatively affect populations of krill predators. Over the past two decades, populations of Adelie and chinstrap penguins have declined significantly on the Antarctic Peninsula, and the average reproduction rate of fur seals in the South Shetlands has slowed as well. Years of low sea ice appear to be associated with low krill production but relatively high populations of salps (a gelatinous zooplankton, of little nutritional value to krill predators).[5] In addition, some predators are dependent upon sea ice to haul out and rest during the over-wintering migrations, and declines and shifts in sea-ice will impact their movements and distributions. Thus, climate-related changes in the environment of Antarctica have had and will likely continue to have important consequences for the marine ecosystems of the region.

Temperate Regions: Climate-induced shifts in species distribution and abundance have been observed in the temperate regions of the Atlantic and Pacific. Many marine fish species have been observed to shift their distributions northward in response to warming waters.[3, 26] Populations of surf clams, an economically important species along the mid-Atlantic coast of the United States (particularly from New Jersey to Virginia), show evidence of increased mortality in the southern regions of their territory. This is thought to be due to elevated sea temperatures.[27] These populations are also susceptible to low oxygen events that may increase in frequency and severity with the anticipated warming in the Mid-Atlantic region. A severe low oxygen event off New Jersey in 1976 caused economic losses of over $70 million to the clam fishery and it was many years before the clam populations recovered.[28] Declining recruitment levels of some species linked to cooler water temperature (e.g., yellowtail flounder in Southern New England) impedes rebuilding of the stock to provide long-term sustainable fisheries.

In the western North Atlantic, a study of the distribution patterns of three dozen pelagic and demersal fish species was conducted using consistent data from over three decades to examine impacts of water temperature changes on geographic distributions.[25] This study revealed a set of species whose center of distribution shifts from 0.5–0.9 degrees of latitude pole-ward for each degree Celsius of water temperature increase. Because not all species responded in this manner, there is likelihood that the structure of predator-prey relationships in the ecosystem would be altered under a scenario of long term warming of Atlantic waters.[17, 24] Studies from the eastern Atlantic have drawn similar conclusions. In the southern North Sea, there has been a gradual replacement of species with primarily cold water affinities with ones previously associated with more southern waters.[29]

In the California Current ecosystem there have also been sustained shifts in the dominance of various fish species over the past few decades. Off California, the dominant fish fauna has shifted from cold-water species to ones of primarily warm water affinities. These changes have occurred gradually over a sustained two decade period, and are confounded by overfishing of many of the stocks.

From the 1970s through the 1990s there were overall declines in the California fishery landings that coincided with an unprecedented period of unusually warm ocean conditions and a decline in ecosystem productivity.[30] Changes in the survival of Pacific salmon appear to follow a decadal-scale cycle (the Pacific Decadal Oscillation, or PDO), with salmon survivorship being relatively high during the cool periods and low during warm periods.[6] In addition the California sardine collapse in the 1940s was driven in part by a shift to cooler conditions and a different ecosystem structure. Ocean sediment records indicate sardine biomass has fluctuated for centuries on time scales associated with decadal-scale shifts in the north Pacific temperature.[31]

Climate and weather patterns over the North Atlantic are strongly influenced by the relative strengths of two large-scale atmospheric pressure cells—the Icelandic Low and a high pressure system generally centered over the Azores in the eastern Atlantic. A deepening of the Icelandic Low often corresponds with a strengthening of the Azores High and vice versa. This see-saw pattern is called the North Atlantic Oscillation (NAO) and a simple index of its state is given by the difference in sea level pressure between the Azores and Iceland.

When the NAO index is positive, we see an increase in westerly winds across the Atlantic and in precipitation over southeastern Canada, the eastern seaboard of the United States, and northwestern Europe.[3] We also see increased storm activity tracking toward Europe. Water temperatures are markedly low off Labrador and northern Newfoundland, and warm off the United States. Conversely, when the NAO index is negative, we have decreased storminess, and drier conditions over southeastern Canada, and colder conditions over the eastern United States and northwestern Europe. Water temperatures are warmer off Labrador and Newfoundland, but cooler off the eastern United States. These changes in the state of the North Atlantic Oscillation show a tendency to persist on decadal time scales. The NAO was generally positive during the 1980s and 1990s but has shown a tendency to decrease since about the year 2000.

Variation in the NAO has very different effects on cod recruitment on the western and eastern Atlantic.[3] The direction of the NAO effect on cod recruitment exhibits patterns consistent with the regional manifestation of the NAO in the North Atlantic, with a coherence in the NAO effect in northern Canada and Iceland and between southern Canada-United States and western Europe. The decline in cod in areas such as the North Sea has been linked to the interplay of over-exploitation and changes in the planktonic ecosystem affecting the food supply of larval cod (which is in turn affected by the NAO). Specifically, the supply of the copepod

Calanus finmarchicus declined during positive NAO conditions and was replaced by smaller bodied species, apparently less suitable as food for larval cod.

In the Northwest Atlantic, researchers have suggested a linkage between oceanographic conditions related to the North Atlantic Oscillation, abundance of the copepod *Calanus finmarchicus,* and the calving success of the endangered right whale in Gulf of Maine.[32]

Abundance of adult *Calanus* declined with these water mass changes and a concomitant decline in the birth rate of right whales was observed. The decline in the calving success comes at a time when other human impacts such as ship strikes threaten recovery of this species. These observations suggest that climate-induced changes can have far reaching ramifications for commercially important fish species throughout the North Atlantic and for critically endangered marine mammal species.

These examples of climate-related effects on marine ecosystems are just a sample from the growing body of evidence linking climate change to marine ecosystem function. All of these changes, whether trended or variable over some time scale, may have profound implications for the health and viability of marine ecosystems and for the human communities that are dependent upon them. It is our challenge to understand these linkages both to better predict their effects and to identify the conservation and management policies in the face of climate variability and change that may help to mitigate their effects.

Various management authorities have responded. For example, the Pacific Fisheries Management Council routinely takes into account decadal-scale changes in marine productivity regimes when setting harvest policies for Pacific groundfish and other species. Similar management responses are being used or contemplated in other living marine resource arenas in which NOAA participates.

Ongoing Challenges for Improving Climate and Ecosystems Information

Marine ecosystems and their component parts have proved to be sentinels of climate change and ocean variability. Changes in living marine resources, when observed at proper scales, give us new information about how changes in climate are affecting the Earth, and have opened new avenues of research into understanding the importance of human activities contributing to these observed changes. It is vital that we improve our understanding of past, current and projected ecosystem impacts of climate change in order to improve the stewardship of these resources. Management policies we use in living marine resource management can either help mitigate or exacerbate changes due to impacts of climate variation. Below I detail a few of NOAA's scientific priorities in improving the predictability of ecosystem responses to climate change.

Regional Climatologies

Regional impacts of climate variability and change are important and are being studied. In fact, some region-specific modeling predicts that part of the planet—and the marine environment—will experience cooler and/or wetter conditions, while other areas will be hotter and drier. Therefore, regional ecosystem responses may result in stable or increasing resources in one region while at the same time resulting in declines in abundance and distribution shifts elsewhere.

Understanding these regional impacts on marine and associated terrestrial ecosystems will require more detailed regional models and data linking global climate variations to regional atmospheric and ocean conditions. This requirement is consistent with NOAA's focus over the last 5 years to integrate multidisciplinary research at the Large Marine Ecosystem level. Eight such marine ecosystems have been recognized in the U.S. Exclusive Economic Zone. It is at the ecosystem scale where we expect to be able to fully realize how anthropogenic effects (e.g., fishing, land use practices, pollution) and naturally driven environmental variation combine to produce the current abundance levels and composition of species in each of our marine ecosystems.

The following will help improve our understanding the ecosystem consequences of climate change:

Improved Climate and Ecosystem Modeling

Extreme weather events as well as long term trends in atmospheric and ocean conditions necessitate that we further improve our predictive understanding of the climate system and its impacts on ecosystems. To do so, NOAA believes that expanded Earth and ecosystems modeling could serve as a tool for studies of: (1) the impacts of climate variability and change on land ecosystems, ocean ecosystems and carbon cycling; (2) the strength of ecological and carbon feedbacks on climate (e.g. the effects of increasing atmospheric carbon dioxide on plant growth, which in turn affects distributions of atmospheric carbon dioxide); and (3) improved predictions of

the impacts of climate trends on regional large marine ecosystems and their species. An expanded Earth and ecosystems model capability would take advantage of the current suite of weather, air quality, climate variability, and ecosystem models to include biogeochemical cycling, dynamic vegetation, atmospheric chemistry, and anthropogenic forcing (e.g. carbon and aerosols) of climate. Existing hydrodynamic models of ocean circulation would be expanded to include trophic interactions, primary productivity, and spatial distributions and movement models for specific taxa, among other ecological phenomena. It would employ a unified modeling framework, enabling integration of a comprehensive suite of physics, assimilation, biogeochemical, and ecosystem model components.

As model development progresses, components will be expanded to include: (a) a land model (currently under evaluation) that simulates dynamic land vegetation and land use changes, as well as the exchange of water and energy between land, vegetation, and atmosphere; (b) a comprehensive ocean biogeochemical model (under refinement) and (c) state-of-the-art marine ecological models incorporating ocean circulation and spatially explicit processes.

Comprehensive Earth-ecosystems models have a wide range of applicability for managers of marine ecosystems, including:

- Short term (6 months to 1 year) and medium term (2–5 year) projections of the regional response of fisheries and protected species to climate change
- Seasonal-interannual prediction of the abundance and distribution of marine populations;
- Seasonal forecasting of coral bleaching potential and assessment of the long-term impact of climate variability and change on coral bleaching frequency;
- Assessments of the health of coastal ecosystems under the stress of pollution and runoff;
- Predictions of harmful algal blooms and eutrophication zones;
- Identification of impact of climate change on species diversity;
- Analysis relating to land use practices and climate;
- Design of marine protected areas and other management measures;
- Predictions of pollution transport and effects on human health; and
- Understanding seasonal patterns of plant reproduction and animal migration.

In order to develop these integrated regional and global models of ecosystem response, we face a number of technical challenges. Additional research to provide the information needed to understand the underlying processes linking climate change to the response of living marine resources is critical. Many of the examples of ecological response cited above are based on statistical correlations of time series of environmental data rather than a fundamental understanding of the complex relationships responsible for the observed phenomena. Predictive models must take such complex dynamics into account. Expanded ecosystem research capabilities will be required to assess these critical links. At the same time, expanded modeling capabilities will require more comprehensive physical observations and related routine monitoring data than we have the capability to deploy today.

Importance of the Integrated Ocean Observing System

NOAA has a large, broad-scale and robust system of oceanographic, climate, and ecosystem measurement stations throughout the U.S. EEZ and the world. To make data from these systems available to climate and ecosystem scientists both within the U.S. and globally, NOAA is working with other Federal agencies and academic and State partners to build the U.S. Integrated Ocean Observing System (IOOS). IOOS, when fully integrated, will provide more complete and improved access to observations of the oceans, including ecological and physical parameters linked to climate variability and change and requisite social and economic information, to serve multiple societal goals. IOOS will support regional climatologies and will provide information necessary to model climate impacts on ecosystems at appropriate global, regional, and local scales. Full development of IOOS is a high priority in understanding climate effects on U.S. marine ecosystems, and contributes to U.S. support of the Global Earth Observing System of Systems (GEOSS).

Management of Living Marine Resources using Ecosystems Approaches

Our current understanding of climate impacts on marine ecosystems points to the critical need to employ ecosystem-based approaches to monitoring, assessing, and managing living marine resources. Climate change is only one of a complex set of factors (both human-induced and naturally-occurring), that influence living marine resources. These include harvesting policies for fisheries, protected species recovery

policies, and management of increasingly complex uses of the coastal zone for a variety of other societal needs. Effective management of resources in this complex environment means we will have to balance many competing and simultaneous objectives. NOAA is committed to advancing an ecosystem approach to its many stewardship responsibilities as a way forward in striking this balance. NOAA defines an ecosystem approach to managing living resources is one that is geographically specified, collaborative, adaptive, accounts for the broad scope of ecosystem knowledge and uncertainties, considers multiple factors affecting resources, is incremental in approach, and balances diverse societal objectives. Incorporating the effects of climate change into the conservation of living marine resources is one of the Nation's greatest and most critical challenges facing ocean ecosystems management.

Thank you Mr. Chairman, I would be pleased to answer any questions you or the other Committee members may have.

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Senator VITTER. Thank you very much, Doctor.

We also have, as I said, Dr. Armstrong. Thank you for being here, as well, Doctor, and please proceed with your testimony.

STATEMENT OF DR. THOMAS R. ARMSTRONG, PROGRAM COORDINATOR, EARTH SURFACE DYNAMICS PROGRAM, U.S. GEOLOGICAL SURVEY, DEPARTMENT OF THE INTERIOR

Dr. ARMSTRONG. OK. Mr. Chairman and members of the Subcommittee, thank you for the opportunity to participate in today's hearing.

I am Dr. Thomas Armstrong, Program Coordinator for the Earth Surface Dynamics Program at the U.S. Geological Survey. I also represent USGS in the Department of the Interior with the U.S. Climate Change Science Program and the Climate Change Working Group of the Arctic Monitoring and Assessment Program.

The USGS strives to understand how the Earth works and to anticipate changes in how the Earth functions. To accomplish this, USGS science aims to understand the interrelationships amongst Earth's surface processes, ecological systems, and human activities. This includes understanding current changes in the context of prehistoric and recent Earth processes, distinguishing between natural

and human-induced changes, and recognizing ecological and physical responses to changes in climate.

The scientific community is largely in agreement that human activity in the 20th and 21st centuries has enhanced greenhouse gas concentrations in the atmosphere and has affected global temperature and climate. But climate change is also a natural, continuous, inevitable Earth process that has occurred throughout Earth's history. Natural climate change is influenced by many forces, one of which is concentration of both naturally-emitted and human-induced greenhouse gases into the atmosphere. In fact, natural climate change has occurred on a regular basis on this planet for millions of years.

Paleoclimate research conducted at USGS and elsewhere has shown that the Earth has experienced several episodes of global warming in the last 800,000 years, during which air temperatures and levels of CO_2 increased in ways comparable to present changes. By studying various parameters or proxies in the prehistoric record, such as tree rings, ice cores, and fossil records, scientists at USGS and elsewhere have developed a detailed record of prehistoric climate change, including changes in temperature and atmospheric CO_2 concentrations over the last several hundred-thousand years. This record shows that natural climate change is generally cyclical in nature, with 40,000- to 50,000-year-long cycles of global cooling and glaciation, punctuated by, typically, 10,000-to 15,000-year-long cycles of global warming and deglaciation, which are often called interglacial periods.

The general consensus among climate scientists is that we are now in an interglacial period with related global warming.

One of the major challenges facing the climate science community today is distinguishing natural change from change imposed upon the natural system through human activities. Although the prehistoric climate record includes temperature conditions comparable to those today, ice core records and other recent scientific findings show that the current concentrations of CO_2 in the atmosphere are now higher than at any time in human existence or in the prehistoric record. This trend suggests a significant excursion from the prehistoric natural climate record that may lead to unprecedented climatic conditions in the future. A better understanding of the causes of this change is necessary before scientists can differentiate between the natural and human-influenced components of present climate change, as well as the potential influence of human activities on future global climate.

Understanding the processes and distinguishing natural variability from human-influenced change is just the first step toward success in the field of climate change. Equally important is effectively communicating climate science to the rest of the world.

Scientists must relay the information, analyses, and, more importantly, conclusions to policymakers, resource managers, and the general public in ways that are both easy to understand and useful. In addition, and very important, scientific findings related to climate change must be delivered in a timely manner so that decisionmakers will be informed by the most relevant, up-to-date, objective information possible. Furthermore, scientists must provide this information with very accurate estimates of uncertainty so

that conclusions and recommendations drawn from scientific studies can be properly evaluated.

The climate science community continues to struggle with development of a consensus on the specifics of the long-term climate future for our planet, but, as we continue to conduct well-planned science to make progress on defining natural climate change and to better distinguish natural from human-influenced climate change, we will gain a fuller and more useful understanding of how climate has changed in the past, how it occurs today, and how it may occur in the future under different sets of human-influenced scenarios.

Thank you, Mr. Chairman, for the opportunity to present this testimony, and I will be pleased to answer any questions you and the other Members of the Subcommittee may have.

[The prepared statement of Dr. Armstrong follows:]

PREPARED STATEMENT OF DR. THOMAS R. ARMSTRONG, PROGRAM COORDINATOR, EARTH SURFACE DYNAMICS PROGRAM, U.S. GEOLOGICAL SURVEY, DEPARTMENT OF THE INTERIOR

Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to participate in this hearing on climate change and its effects on terrestrial and marine systems. My name is Tom Armstrong, and I am the Program Coordinator for the Earth Surface Dynamics Program at the U.S. Geological Survey (USGS). I also represent USGS and the Department of the Interior as a member of the U.S. Climate Change Science Program and the Climate Change Working Group of the Arctic Monitoring and Assessment Program.

The USGS strives to understand how the Earth works and to anticipate changes in how the Earth functions. To accomplish this, USGS science aims to understand the interrelationships among Earth surface processes, ecological systems, and human activities. This includes understanding current changes in the context of prehistoric and recent Earth processes, distinguishing between natural and human-influenced changes, and recognizing ecological and physical responses to changes in climate.

We conduct scientific research in order to understand the likely consequences of climate change, especially by studying how climate has changed in the past and using the past to forecast responses to shifting climate conditions in the future. My testimony today will address three major sets of challenges:

1. Distinguishing natural from human-influenced climate change;
2. Understanding ecological and physical responses to climate change, and predicting the related impacts of these responses on climate; and
3. Effectively conveying cutting-edge climate science to policy-makers, decision-makers, and the public.

I will conclude my testimony with a brief discussion of the state of our understanding of climate science and how this provides a roadmap to our future understanding of long-term climate change and its impact on people, natural resources, and the Earth.

Distinguishing Natural from Human-influenced Climate Change

In a statement on behalf of the Administration to the Senate in July, 2005, Dr. James R. Mahoney, now former Assistant Secretary of Commerce for Oceans and Atmosphere, and Director of the U.S. Climate Change Science Program, stated, "We know that an increase in greenhouse gases from the use of energy from fossil fuels and other human activities is associated with the warming of the Earth's surface." This statement underlies the growing public debate on climate change: are humans and their activities the driving force behind global warming? The scientific community is largely in agreement that human activity in the 20th and 21st centuries has enhanced greenhouse gas concentrations in the atmosphere, and these added gases have an effect on global temperatures and climate. Climate change is also a natural, continuous, inevitable Earth process that is influenced by many forces, one of which is the concentration of both naturally-emitted and human-induced greenhouse gases in the atmosphere. Many other forces also control climate change, including cyclical changes in solar radiation, movement of the Earth's tectonic plates, oscillations in

ocean temperatures and ocean currents, and the positions and magnitudes of meteorological entities such as high, low, and convergent zones. In fact, natural climate change has occurred on a regular basis on this planet for at least the last 800,000 years and possibly much longer. Paleoclimate research has shown that the Earth has experienced several episodes of global warming in this timeframe during which air temperatures and levels of CO_2 increased in ways comparable to the present day changes, although the ice record indicates that the current concentrations of CO_2 in the atmosphere are unprecedented during human existence. Understanding the science of natural variability in climate is essential to the formation of effective policy regarding the mitigation of or adaptation to climate change, both human and natural.

One of the major challenges facing the climate science community is distinguishing natural climate change from that imposed upon the natural system through human activities. This science must also develop an effective understanding of the consequences of the human-induced component. The science we conduct in order to understand both the human component of climate change and its potential impacts on the natural climate system is known as climatology; *paleo*climatology looks into the prehistoric past of the Earth in order to determine how climate change occurred prior to human activity. Through paleoclimate studies, scientists have been able to determine that climate changes naturally, and that there indeed are natural climate cycles that have occurred regularly, and in a predictable fashion, over at least the last 800,000 years of Earth history.

By studying various parameters, or proxies, in the prehistoric record, such as tree-rings, ice-cores, and fossil pollen records, scientists at USGS and elsewhere have been able to develop a detailed record of climate change, including changes in temperature and atmospheric CO_2 concentrations over the last several hundred thousand years (Figure 1). This record shows that natural climate change predates human influence and is generally cyclical in nature, with long-term periods of global cooling and glaciation (40,000 to 50,000) years long, punctuated by shorter-term periods of global warming and deglaciation (10,000 to 15,000 years in duration). The general consensus among climate scientists is that we are within a new interglacial period with related global warming.

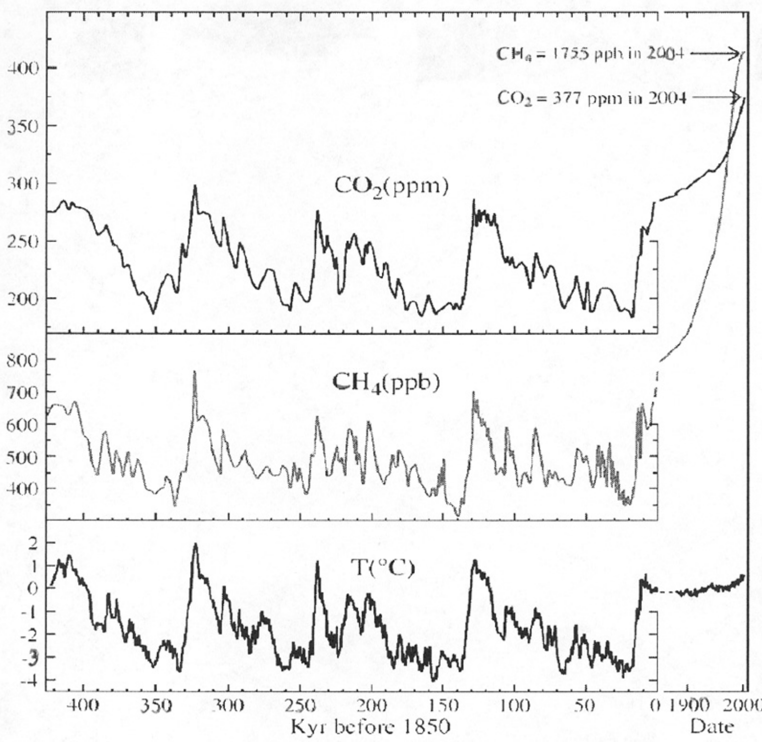


Figure 1. CO_2, CH_4 and estimated global temperature from Antarctic Ice core record (graph from Hansen, 2005)

Ecological and Physical Responses to Climate Change

A second set of very important challenges relates to developing a better understanding of how the Earth and its physical and biological processes respond to climate change over the short-term and well into the Earth's future. Scientific research conducted over the past several decades reveals that climatic changes are part of a larger interactive system of changes in ecosystems, oceans, glaciers, atmospheric chemistry, and many other components. The geologic record provides information on how this complex system has operated over time and clues to the potential causes of change. By looking back into the Earth's geologic record, scientists have been able to determine how ecological and physical systems and processes change, adapt, or terminate as climate changes; and how these responses can alter climate (known as a feedback mechanism). Many of these climate changes are gradual and continuous, with ecological and physical responses occurring over hundreds or thousands of years. Some of these climate changes are abrupt, spanning decades, with the resulting ecological and physical changes being short-lived but very dramatic.

Some examples of responses and feedbacks to climate change include:

- The temperature of the United States has increased by an average of less than 1 degree Celsius during the past 56 years, with much variation among regions. For example, Alaska has experienced an average warming of 4 degrees since 1950, more than 4 times the U.S. average of 1 degree.
- The higher the latitude, the greater the increase in temperature. Of particular concern are the rapid changes occurring in northern latitudes, where temperature changes have been greater than elsewhere on the globe. Permafrost is thawing and has the potential of releasing significant amounts of carbon dioxide

to the atmosphere and nutrients to the coastal ocean. Decreasing ice cover is exposing coastlines to rapid erosion and the Arctic Ocean to accelerated warming. The USGS and the U.S. Forest Service are initiating a multi-agency, multidisciplinary research and monitoring effort to track and understand these changes in the Yukon River Basin in Alaska and northwest Canada. The Yukon Basin will serve as a benchmark landscape for interpreting and responding to rapid climatic, hydrologic, and ecological changes occurring in Northern latitudes.

- Decreased cloud cover in the northern latitudes related to climate change correlates to decreased snow levels, less solar reflection, and thus greater melting of snow, glacial ice and permafrost. This creates an additional feedback mechanism where more melting leads to greater atmospheric water vapor, which in turn leads to a warmer atmosphere.
- Over the last 50 years, climate change in the northeast (Maine and New Hampshire) and mountain-west (Washington and Oregon) of the United States has led to between 8 and 17 percent declines in annual winter snow pack. The physical response to this decline includes decreased recharge of the ground-water systems, decreases in surface-water flows, increased stress to public water systems, changes in the timing of river ice-outs, and significant impacts on the spawning environments for fish such as Pacific and Atlantic salmon.

The Effective Conveyance of Climate Science to Policy-makers, Decision-makers, and the Public

Scientists must relay relevant information, analyses, and conclusions to policy-makers, resource managers, and the general public as a whole. Besides global warming, other ecological and physical consequences of climate change may include strong storms, sea-level rise, droughts and floods. If scientists can better inform decision-makers about what to expect from climate change, this will effectively enhance the development of short- and long-term strategies for protecting the public welfare and maintaining healthy and viable ecosystems and natural resources. For instance, studies conducted by USGS and others are showing that sea-level rise will continue to impact coastal zones throughout the world. Present and future resource managers will need to take into consideration this scientific conclusion when developing an adaptive management strategy for restoration and long-term stewardship of land, water, and biological resources.

Scientific findings related to climate change must be delivered in a timely manner so that decision-makers are informed by the most relevant, up to date, objective information possible. Furthermore, scientists must provide this information with very accurate estimates of uncertainty so that conclusions and recommendations drawn from scientific studies can be properly evaluated. The U.S. Climate Change Science Program, of which USGS and the Department of the Interior are members, is actively involved in developing a more effective decision support strategy for all interested stakeholders.

The Future of Climate Change

Understanding the paleoclimate history—where we look at climate information well beyond the 50 to 100 year instrumental record—is important because it provides us a natural climate baseline from which to work. The instrumental record provides us only a momentary glimpse of the entire picture of past and future climate change. We need to understand what has happened in the past in order to forecast future short- and long-term climate trends. Once the baseline has been established we can then begin to distinguish the human-induced factors that must be considered. This information then allows us to validate model predictions of past climate change and use that information to develop better-constrained models to forecast the effects of future climate change, and related ecological and physical responses and feedbacks.

For all of the information we have gathered, and for all of the understanding of climate change that we have developed, the climate science community continues to strive toward development of a consensus on the long-term climate future for our planet. Given our current scientific understanding of climate change, the following are areas in which USGS science can make a valuable contribution:

- Determining the baseline physical, chemical, and ecological conditions of the Arctic and Subarctic. Without new baseline data and monitoring infrastructure, our ability to determine what changes are occurring in northern latitudes, and our capacity to help society develop cost-effective adaptations to those changes, may be greatly diminished.

- Developing decision support systems for the impact of sea-level rise. Current research concludes that sea level rise will continue. Since sea-level rise is already having impacts on some ecosystems and human communities, decision support systems will be critical tools for planners to anticipate levee construction or relocation of shoreline infrastructure.
- Focusing attention on the potential changes in the most vulnerable regions and systems (e.g., polar regions, coastal zones, and the tropics), and assessing regional impacts of long-term climate change.
- There might be surprises: critical thresholds in Earth and biological systems may be abruptly reached that have long-term or even permanent consequences.
- Adaptation strategies can minimize negative impacts of natural climate change, as well as the impacts of human-induced climate change; mitigation may work to quell human-induced climate change and variability.
- Although possibly successful, mitigation of natural changes may very likely lead to unforeseen additional problems unless the system under study is extremely well understood.

Thank you, Mr. Chairman, for the opportunity to present this testimony. I will be pleased to answer questions you and other Members of the Subcommittee might have.

Senator VITTER. Thank you both very much.

I'll open it up with questions, and pose this question to both of you. Where do 20th century measurements and trends fall in the very, very long-term historical record, in terms of previous natural historical cycles?

Dr. ARMSTRONG. Senator, I'll go first.

The current conditions of temperature fit within what we see in terms of cycles of climate change over the last 400,000 years. We need to look at climate both in terms of long-term climate change over a long-term many thousands-of-years in order to distinguish various long-term natural climate cycles, but also to distinguish those long-term cycles from human-induced change. But temperature is a component that is on—in the realm of what we've seen in the prehistoric past.

What is most unique, I think, is that the temperature is out of alignment with the present CO_2 concentrations and methane concentrations that we see in the atmosphere. Those, according to the most recent scientific information, are at unprecedentedly high levels compared to the prehistoric past.

Senator VITTER. Doctor?

Dr. MURAWSKI. Just look at the shorter time cycle, the last 10,000 year, since the last ice age. The current temperatures and current amount of precipitation is actually the highest levels that we've seen in the last thousand years.

Senator VITTER. But that's sort of one cycle. I guess what I'm asking is, If you look at previous historical cycles, including peaks, is this—fall within those boundaries, or not?

Dr. MURAWSKI. I agree with the testimony that Dr. Armstrong gave, in terms of long-term cycling of——

Senator VITTER. Right.

Dr. MURAWSKI.—ice ages that have come and gone.

Senator VITTER. What would be the temperature point or line beyond which this current trend would clearly be moving beyond previous historical experience?

Dr. ARMSTRONG. I can get the specific information for you.

But I can say, offhand, that we are—within the uncertainties that we have from the geological record, we are on par for being

at the peaks of what we've seen in long-term climate cycles. We are at a peak, in terms of temperature. If it goes much higher than what we see today, we will be getting into that realm within the uncertainties of the information we have in the past, where temperatures will reach unprecedented levels. But it really—I want to stress, Senator, that it is the CO_2 and the methane levels in the atmosphere that are significantly higher than what we have seen in the prehistoric record.

Senator VITTER. Right. Right. But, of course, one of our biggest concerns about those levels is impact on temperature.

Dr. ARMSTRONG. Correct.

Senator VITTER. And so, that's why I'm——

Dr. ARMSTRONG. That is correct.

Senator VITTER.—asking about impact on temperature.

Dr. ARMSTRONG. Right. And that is something that USGS science looks a lot at the past record, and we see that there is a coincidence between changes in greenhouses gases naturally emitted, obviously, in the prehistoric record, greenhouse gas concentrations, and temperature changes. They do mimic each other. What—if we look at the present scientific literature, the most recent information from ice core records and other information, there seems to be a disconnect now between levels of greenhouse gases, which are going up, compared to what we see with temperature.

Senator VITTER. OK. Also, another pretty broad question for both of you. What's each of your opinions regarding the state of science, in terms of climate models? Obviously, in terms of your projection to the future and impacts that it could have on the environment and animals, as well as human populations, we need to depend on certain models and predictions. What's your assessment of the current state of the accuracy and fine-tuning of those models?

Dr. MURAWSKI. We see a convergence of many global climate-change models that are being run now, and we see a general convergence in the results. In fact, there was a paper published in *Nature* a couple of weeks ago that looked at the various model runs and looked at their assumptions. And we do seem to be closing in on the general range of temperature increases that'll be there.

That being said, we know that we have to do more, in terms of the modeling, in terms of understanding regional impacts, because that's what's so important for the ecosystems, both terrestrial and in the ocean, how the regional climatologies will influence what goes on, because even the global models that we have now, are indicating some places will be wetter and cooler under a general rise in Earth's temperature. And so, we need to understand and step those models down into the regional size to understand the regional ecosystem impacts better.

Senator VITTER. And I assume—Doctor, before you answer—I assume part of this analysis of modeling is how a model predicts past behavior. And how do they? How do the best models we have developed to date compare, in terms of predicting past activity?

Dr. MURAWSKI. Well, I'm not a climatologist, so I'll pass on that one. We can certainly get that information back to you.

Senator VITTER. OK.

Doctor?

Dr. ARMSTRONG. Yes, I would actually like to go back to what Dr. Murawski was saying about the articles in *Nature* by Dr. Overpeck and other scientists. There are several in the journal, *Nature* and *Science*.

One of the global circulation models that was used in this paper was doing just what you asked, Senator, and that was looking—using the current model framework and incorporating the geologic record, the prehistoric record into the model, and found that, as they put in various parameters from the past into the framework of this model, including starting conditions and intermediate and long-term conditions, they were able to mimic very well the proxy record or the conditions that the—you would predict, that we know occurred in the past, and then take that, in turn, and look toward the future. And I would say that's one of the things at USGS that we—I would have to say are—have been critical of in the past with research, is that some of the research hasn't really looked at the natural variability of systems as effectively as it needed to. And I think these papers, by Dr. Overpeck and others, are a real significant breakthrough in the use of the paleorecord in order to better understand or calibrate to the past to predict into the future.

Senator VITTER. OK.

Dr. Murawski, in your testimony you mentioned, somewhat in passing, that subsidence in Louisiana, which I'm obviously very interested in, is attributable to hydrocarbon recovery in coastal areas. I've talked to some experts down there who also say that there is long-term natural subsidence unrelated to more recent activity. Would you like to comment on how you think those two factors contribute, in terms of subsidence in coastal Louisiana, in particular?

Dr. MURAWSKI. Sure. There are a lot of factors that are influencing the rate of sea-level rise there. And, of course, coastal Louisiana is the hotspot for sea-level rise throughout the country. Obviously, you've got the issues of the reduction in sediment coming down the Mississippi and other major rivers, which are contributing to the marshlands being reduced in size. You've got all sorts of exploration and production activities that are creating voids there, that contribute to subsidence. And then, you've got general sea-level rise. And so, it's the mix of those three factors that's important. And, of course, we're trying to mitigate sea-level rise issues in the coastal marshes down there, because they're so important to the marine fisheries of the Gulf area, because most of the species there are estuarine dependent. That means their juvenile nursery areas are in those marshes, and they're so important.

Senator VITTER. In terms of the relative significance of the various factors, do you think there is a scientific consensus about it? Because obviously that drives, in part, what we might do to stop it or mitigate it.

Dr. MURAWSKI. Well, there has been a lot of work in trying to look at those relative factors, and they're probably playing out differently in different locations. Obviously, the reduction in sediment load in the Mississippi over the last century has been very significant, in terms of that, but, of course, you know, in various places the balance of those factors may play out differently, just because of the nature of those activities, the very local, you know, exploration activities, et cetera.

Senator VITTER. OK, thank you.

Chairman Stevens?

The CHAIRMAN. In terms of looking at the long, long, long history of the world, what is the—sort of, the period of time that the cycles have taken place? One of you go back 30- to 40,000 years. How far back do you go, in terms of your measurements?

Dr. ARMSTRONG. Well, the science that I was referring to, Senator, we were looking back over the geologic record 400- to 800,000 years, and obviously the farther back you go, the less perfect the record, the lower our resolution, and the higher our uncertainty, which is important to clearly define.

There are different cycles related to different things—orbital forcing, solar insulation. These cycles occur on time periods of cycles of 100,000 years, 40,000 years, 17,000 years, possibly 9,000 years. But these cycles combine to present what is a very regular cyclical pattern over that long-term geological record.

The CHAIRMAN. If I understood Dr. Armstrong, if you compare the current period to the distant past, there still are some cycles where the highs and lows and the differences would be similar to what we're—we've gone through in the past. Is that right?

Dr. ARMSTRONG. That's correct. That's in my written testimony, as well, at figure 1. Absolutely so.

The CHAIRMAN. So, we could—then we could be either at the top of the cycle and going up, or we could be at the top of the cycle and starting to turn down.

Dr. ARMSTRONG. The—one of the problems you'll see, even in figure 1 of my written testimony, is that if we try to telescope too much the instrumental record, be it 40 years or 100 years, we're looking at a very short period of time in that long-term climate cycle. It is not much information, in terms of the long period of time. And without that geologic—that paleoclimate information, we really can't deduce the long-term cycle. That's why the ice core analyses, both from west Antarctica and Greenland, have been so invaluable to us in understanding long-term climate cycles, because those cycles are much, much longer than the instrumental record itself.

The CHAIRMAN. All right. As you say—if your number-one challenge is to distinguish natural from human-influenced climate change, right?

Dr. ARMSTRONG. I believe that is one of our major challenges, yes.

The CHAIRMAN. What do we need to do to do that job better?

Dr. ARMSTRONG. I think one of the things that we've been trying to do at the USGS—and I know that other people at NOAA, with their group on paleoclimate, and academia, are trying to develop better proxies or better indicators of past climate conditions, and certainly a better handle on age uncertainties of the climate record itself, so that we can have a higher resolved, more accurate understanding of when changes occurred, exactly, or as close to exactly we can in the geologic record, and what were the exact conditions that occurred, both in terms of temperature or gas concentrations or other valuable pieces of information, including ecological responses to climate change over the geologic record.

The CHAIRMAN. Well, Dr. Akasofu's volcano observatory can give us a prediction of how soon a volcano may erupt, but we can't get a prediction over a period of years ahead how often is that going to happen. Those are natural emissions, right? Now, do we need any more measurements to determine how much is natural and how much is manmade on—from the natural side?

Dr. ARMSTRONG. My opinion is, yes, we do. We need more science that can distinguish—first, truly understand natural variability, natural climate change, because that baseline is not static, it is not flat, it is changing. It's constantly changing. It may not change a lot on a daily basis or over 100 years, but at times it can be abrupt or it can occur dramatically over 1,000 years. Having more information on that natural baseline and how it changes and will change over time is critical to understanding what the additive effects of human activities are on global climate, and as Dr. Murawski said, on regional climate, as well.

The CHAIRMAN. All right. Dr. Murawski, you're more connected with the ocean side of this, right?

Dr. MURAWSKI. Right.

The CHAIRMAN. Which is two-thirds of the world's surface, right?

Dr. MURAWSKI. Right.

The CHAIRMAN. Do you really think you have the ability to measure that two-thirds today?

Dr. MURAWSKI. Well, one of our proposals, obviously, is to try to improve the observing that we're doing in the ocean side through the Integrated Ocean Observing System and other things. We're trying to take more and more physical measurements and correlate them with a more dense biological observing system, as well. I mean, we're trying to measure things like changes in walrus distribution and whale distribution in the Bering Sea, along with the fish species, crab species, and other things. It's a——

The CHAIRMAN. I'm a fisherman. I think the whales and mammals go where the fish are, just like we do. But I'll put that aside.

What do you think you need, in terms of ability to measure the oceans, that you don't have?

Dr. MURAWSKI. Well, we need a lot more dense observation network, in terms of physical measurements—basic buoys, the sea surface temperatures from satellites. Next generation, we need the basic tools to measure the biological processes that we're looking at. They need to be more dense. They need to be distributed around the coasts. We have a system that's about 50 percent built out at this point, in terms of measuring the various parameters, both on the physical——

The CHAIRMAN. Right.

Dr. MURAWSKI.—side and——

The CHAIRMAN. Last question, I'll—I've got a lot more questions, but I'll only ask one more. I'm sure you're familiar with what Dr. Sylvia Earl is doing with her submersibles. Are we learning anything from those submersibles, in terms of what's happening in the deep sea, as compared to what's happening on the surface?

Dr. MURAWSKI. Well, in terms of the deep sea, obviously, you know, this is one of the most unexplored areas on the planet. Now, we have an ocean exploration project in NOAA that we've been trying to nip away at, understanding deep coral reefs and other

things. We're learning that, there's a lot more biological diversity down there than we have anticipated. For example, the coral gardens off Alaska, in the deep water, were unknown to science until we started poking around in the deep water. We definitely need a research program that looks not only at the coastal ocean, but the deeper ocean, as well.

The CHAIRMAN. Well, I've just—I lie a little, that that was my last question. What's the impact of changes in the deep sea, as far as human experience, compared to that on the surface? Is there anything going on down there we should—we really should be excited about?

Dr. MURAWSKI. Well, one of the things that we need to be careful about is this new discovery of these deep coral gardens that we see in the deep oceans. Those deep cold-water corals are at risk to increasing acidification of the ocean, because those corals are formed by the accumulation of calcium carbonate. And if, in fact, the calcium carbonate budget of the deep ocean is going to decline, particularly in the polar areas, which some of the projections indicate, then they could be at risk for long-term climate change.

The CHAIRMAN. Well, I have a bill to authorize further ocean exploration to deal with that kind of research. Unfortunately, we have a Senator that doesn't want anything else new authorized, thinks there are too many programs already authorized. So, we'll probably have to wait until we solve that problem.

Thank you very much, Senator.

Senator VITTER. Thank you, Mr. Chairman.

Senator Lautenberg?

Senator LAUTENBERG. Thanks, Mr. Chairman.

I'm sorry I didn't hear all of the testimony that each of you gave, but I've read through, and I would just like to ask you, What do each of you think about the widest differences of view for those who don't see any real alarm out there, as opposed to those who are—who feel that this is a matter of great urgency? Are we now being forced to take actions, if I may use the expression, before it's too late, in terms of the climate change in—that we're seeing?

Dr. MURAWSKI. As I said in my verbal testimony—and I'm sorry you weren't here—these factors of increasing acidification of the ocean, sea-level rise, changes in the distribution of animals are all sources of concern that we have to have, in terms of the ecosystem effects of climate change.

Senator LAUTENBERG. Serious concern.

Dr. MURAWSKI. Certainly.

Senator LAUTENBERG. Urgent.

Dr. MURAWSKI. The urgency of the issue depends on the issue, in terms of where we are.

Senator LAUTENBERG. Well——

Dr. MURAWSKI. We have a number of issues——

Senator LAUTENBERG.—because we have a debate, an honest debate among us in the Senate, those who think that, as I said in my opening remarks, that we're going to endanger our economy. And I have a comma, and that is, "if we're still alive after that." And so, you know, the—I'm, kind of, one of those who could be called an alarmist. The principal reason for that is, I have ten grandchildren. They're very young. And we love the outdoors in my

family. And it's not simply going for a swim or fishing. I have a grandchild who has asthma fairly severely, and we have to be very careful when he over-exercises or what have you. And now, is the world that we're looking at going to endanger his health even more? We see a—substantial rises in the number of juvenile asthmatics and other autoimmune diseases that are connected to the respiratory well-being. Is that—might we expect a turnaround in things and suddenly see the air start to clear up? Or will we be looking at face masks along the way?

Dr. MURAWSKI. Well, obviously we're concerned about issues like oceans and human health. That's a new, emerging set of sciences that we're trying to understand the ramifications of how changes in ocean systems influence the prevalence of disease, the relationship of atmospheric issues to ocean changes, et cetera. And those are obviously areas of emerging science and emerging interest, in terms of you and others.

Senator LAUTENBERG. Dr. Armstrong, do you have any comments about my question?

Dr. ARMSTRONG. Yes, sir. And I am—I'm sorry you missed my oral—part of my oral testimony——

Senator LAUTENBERG. I am, too.

Dr. ARMSTRONG.—as well. I think the issue that you're really getting at here, first and foremost, is the disagreement on how much of what we're seeing today—and Senator Stevens said it, we've heard it in testimony—I don't think there's much disagreement that there is ecological and physical response to global warming, to climate change. There are responses. There always have been responses. The question becomes, What is natural change and response, and what is human-induced change? And I think the question really becomes, Can we distinguish between natural climate change or climate variability and that influenced or induced by human activity? And that is something that I think we still have a fair amount of disagreement of, is, How much of each of those components plays into what we see today? But we recognize that both have a very large role, and we need more science to really help distinguish that. But, beyond that, sir, I'd have to say that, as a scientist, it isn't my job to define urgency or what mitigation or what policy needs to occur; rather, provide you with the science you need in order to—you and others—to make those decisions.

Senator LAUTENBERG. Well, if we know that human activity causes a significant part of the changing climate that we see, are we wise to, instead of trying to balance the scales and see which comes from where, to get on with that part that we can deal with and accept some of the natural responses that we get? Shouldn't we focus on that part, that we know the reduction of the effects of the human production of problems to the climate—wouldn't it be a good idea to get going on those things and——

Dr. ARMSTRONG. I agree that in order to mitigate, you need to understand what you can mitigate. And science can help provide the information you need in order to understand what it is that can be mitigated and what are the things that may have to—we may need to adapt to. But in terms of what those are, I believe that we just need to provide you with the best, most relevant science to make those decisions.

Senator LAUTENBERG. Well, if there's a fire at home, and you know that it's going to engulf you, and—what you do is, you immediately respond to getting the fire out, and not try to just run through the house and find the coolest place. And, you know, when I see what I think are the irrefutable results of life as we know it, is that when we look at places like Glacier National Park and we see that it won't be too long before there are no more glaciers in Glacier National, or if we see Kilimanjaro, if we see places in Greenland where shelves of ice are floating away and leaving something different—and then Senator Stevens—there are few who are better naturalists than Senator Stevens, but Alaska is a place with its abundant beauty, but also there are obviously problems arising. And when I see what's happened—there was a—and I'm not sure which of the programs I was watching—the polar bears, and how their reductions in weight is endangering their existence, and cubs are born less—in smaller numbers than they used to be—commonly two or three at a time, now it's barely one at a time, and the reproduction rate is substantially reduced. When I see things like that, it—I must confess you, it scares me.

Now, am I correct in saying of the hottest years on record, 19 occurred in the 1980s, or later, and three of the warmest years on record, average global temperatures, in 1998, 2002, and 2005? Stop me if I'm incorrect with any of these. 2005 was the highest annual average temperature worldwide since instruments—instrumental recordings began, in the late 1800s. To your knowledge, are those statements correct?

Dr. MURAWSKI. I believe they're accurate.

Dr. ARMSTRONG. Yes.

Senator LAUTENBERG. Don't know?

Dr. ARMSTRONG. I believe they're accurate.

Senator LAUTENBERG. They're accurate. Did you say you weren't sure——

Dr. ARMSTRONG. I said I believe they're accurate.

Senator LAUTENBERG. Oh, OK. Well, the—that tells me that we've got to get going.

I would ask if any of you have—it's—Mr. Chairman, you've picked an interesting subject on the—it's one that should absorb even more attention than we're giving it—have you—either of you been approached by NOAA scientists who are concerned that we're not doing enough to address the threat of global warming?

Dr. MURAWSKI. I'll take that issue. Obviously, you know, we have 5,000 scientists in NOAA, and we give scientific opinions on a lot of different issues. And we have a lot of intense debate about these issues, in terms of what we're trying to deal with. Admiral Lautenbacher, who runs the agency, has expressed to all the staff the importance of having open debate, in terms of these issues of policy. Our corporate culture is, trying to make sure that the science is available. We have an interest in making sure that our science is peer-reviewed. And so, once it's peer-reviewed, it's generally available in the public. And, you know, we publish that science, and we make it widely available within the climate-change science program and elsewhere. And so, that's our corporate policy, in terms of dealing with the science that we produce.

Senator LAUTENBERG. Dr. Armstrong, have you been approached by anybody from the USGS registering alarm at the pace of our response to climate change?

Dr. ARMSTRONG. In terms of the pace of conducting our research?

Senator LAUTENBERG. Yes.

Dr. ARMSTRONG. No, sir, I have not.

Senator LAUTENBERG. Oh, everybody—that—they think that we're moving at the right pace, investing enough resources in doing that, is that—is that your view?

Dr. ARMSTRONG. I—the scientists who I personally fund and am responsible for, I believe—we have not had an open discussion about that, but I can say that they feel that they're adequately funded to do the work that they have at hand, yes, sir.

Senator LAUTENBERG. Dr. Murawski?

Dr. MURAWSKI. I think we have a fair difference of opinion in our agency, as any individual science would have a difference of opinion about their research and the importance of their research. And, obviously, we have to balance what we can afford with what Congress gives us to do our work.

Senator LAUTENBERG. Just one last thing, Mr. Chairman.

Do we have obvious examples—and you may have had this in your testimony—commercially significant fish and shellfish, their responses to acidification—are these species at risk as a result of the changing acid levels in ocean waters?

Dr. MURAWSKI. Well, it's interesting, because we had a similar event about 55 million years ago, in terms of the rising acidification——

Senator LAUTENBERG. I know I'm old, but I don't remember that.

Dr. MURAWSKI. Neither do I. And what we saw was rapid loss of species of plankton that are the base of the food chain. And so, we're concerned that as acidification rises, that we will see not only issues with various plankton species, which support the food web, but also the deep corals, which are potentially at risk, as well.

Senator LAUTENBERG. Thanks, Mr. Chairman.

The CHAIRMAN. Could I just——

Senator VITTER. Sure. Mr. Chairman?

The CHAIRMAN. I don't want to be obtuse, but, Doctor, I had a briefing from the BLM that located a site in northern Alaska where there is a promontory that they decided was—I'm sure you know about it, Dr. Armstrong—a watching place for hunters who used to hunt dinosaurs——

Dr. ARMSTRONG. Yes.

The CHAIRMAN.—and such animals. Now, I don't want to offend you, but what if, at that period, someone had gotten alarmed about the rate of change and tried to disturb the natural occurrence of change? Are we in a similar position?

Dr. ARMSTRONG. Senator, I think that, as I said, if natural change is inevitable, and it's part of just the Earth's engine and its processes, then we do need to understand what it is that we are dealing with. We need to understand, as best we can, what is natural change, versus human-induced change, because if we do try to mitigate natural issues, natural change itself, if we do not understand, in totality, the system in which that natural change is occur-

ring, there may be unforeseen complications or other problems that occur due to the mitigation itself.

So, my point is not to say that we should not mitigate. My point is not to say we shouldn't adapt. My point is simply that the science needs to inform you as to our best understanding today what is natural change, what do we believe is—based on the scientific information with the degrees of uncertainty we have today, what is the human-influenced part of climate change, so that the people that are really the ones responsible for mitigation and policy on adaptation can make those decisions in an informed environment.

The CHAIRMAN. Well, thank you. That's my hope, that we'll concentrate not just on the change that's caused by man, but concentrate on trying to understand how much of it is natural.

Doctor?

Dr. MURAWSKI. Yes, I'd like to comment on that. I think we're already starting to see some of our public resource agencies stepping out on this and trying to accommodate, you know, changes in the Earth's climate, in terms of the fishery management, for example. And one good example is, in the Pacific there is a phenomenon known as the Pacific decadal oscillation, which is a climatological feature that varies the climate between Alaska and the Pacific West Coast. The fishery managers there know that this happens from time to time, and the productivity of the stocks goes up and down when these cycles change. And so, what they're trying to do is put in polices that recognize when these cycles are changing back and forth, and shift the management accordingly, so that you don't over-harvest in times when it's poor, or you take advantage of, when the cycle is actually favorable.

The CHAIRMAN. Absolutely. That's what my interest is.

Thank you very much.

Senator VITTER. Just final wrap-up questions.

Dr. Armstrong, I'm really very interested in your figure 1 in your testimony. And, looking at that, one obvious question that jumps out is, What might the lag time be between CO_2 rises and CH_4 rises and temperature rises? Is the past historical record from Antarctic ice cores or anything else with regard to high temperature periods clear enough to tell us, in a pretty narrow number of years, which is what we're experiencing in the 20th century, what that lag might be so that, you know, we have some beginning of an understanding of whether the temperature chart is about to spike or not?

Dr. ARMSTRONG. Senator, I will—before I give you my answer, I'd like to say that I think several of the people, including Dr. Corell, on the second panel, are outstanding scientists who ask that very same question, too, and will have some very—a more accurate estimate for you, or a more insightful prediction.

But what I will say is that there is a significant amount of debate in the scientific literature itself about whether or not the next—the current interglacial we're in now is one that will—is similar to the past, in terms of frequency and in terms of duration. There's a fair amount of debate over that. There are some scientists who have published recently—in the past 15 years, that have said that, based on predictions of orbital forcings and solar in-

sulation, that we may be looking at a longer interglacial this time than what we've seen in the last 400,000 years, and that it is, in fact, a unique natural cycle that we're going into.

I'm not enough of an expert on that field to give you an opinion on that, but I would say that that, in itself, is something that we need to look into more specifically, as to nail down just what will the next 15- to 35,000 years look like in terms of the natural climate change, and how will, with increasing greenhouse gases that I think we all agree we're seeing in the instrumental record—how will those impact temperature along with the natural cycle over the next 100,000 or tens of thousands of years?

Senator VITTER. What about the very narrow question I posed about the lag time, if any, between CO_2, CH_4, and temperature? Is the historical record, you know, going back a long time to previous high temperature eras, precise enough for us to know anything about that?

Dr. ARMSTRONG. I would say that it almost becomes a moot point, sir, because of the additive effect of the human-influenced greenhouse gas emissions, that we need to have a better understanding of what the response will be to the combined—the additive and the cumulative—effect of natural and human-induced greenhouse gases. And I will defer to Dr. Corell on that question. I think you'll get an accurate—a better understanding of the answer to that question. I do not have estimates for you.

Senator VITTER. OK. Well, what I'm getting at, I don't think is a moot point, because it basically goes to whether, at the end of your figure 1, we're going to experience a spike in temperature or not.

Dr. ARMSTRONG. I do not have the answer to that question. That—I didn't mean to infer that that—you know, your question was a moot——

Senator VITTER. Right.

Dr. ARMSTRONG.—point. It's not. It's a very important point. And it really need—we need to have a better understanding from the people that are conducting the models and forecasting forward, what will be the additive effect in this case, in this interglacial——

Senator VITTER. Right.

Dr. ARMSTRONG.—which is unique because of the human activity on this planet. What will be the additive effect to both greenhouse gas emissions for the future, and, therefore, the impact on temperature—global temperatures, for the near future and the long-term future? I do not have the answer to that question, sir.

Senator VITTER. Thanks. And I'd invite, ahead of time, the second panel to respond to that question, too.

And, Dr. Murawski, in the Magnuson-Stevens reauthorization, I've included some authority for restoration work for fish habitat, particularly with the hurricanes and other events in mind, that would go through the National Marine Fisheries Service, through NOAA. Do you have any comment about the usefulness of that sort of work?

Dr. MURAWSKI. Well, as you know, NOAA is involved in a number of activities for restoration. There is quite a vigorous program in Louisiana, in particular, that's—the Army Corps of Engineers, NOAA, USGS, and the State of Louisiana are involved in some-

thing called CWPPRA. And CWPPRA is quite successful. This is the Breaux bill. It funds about $55 million a year, in terms of habitat restoration. And the projects that we're responsible for in CWPPRA, have been quite successful. In fact, they negotiated the hurricanes quite well, in terms of the design of their properties. And we see that coastal restoration can work in those areas, that we can mitigate against sea-level loss and loss of those marshes by projects that go through that sort of process, where we get the best projects, and the highest priority ones.

Senator VITTER. Great. Thank you all very, very much. Appreciate your testimony.

Dr. MURAWSKI. Thank you.

Dr. ARMSTRONG. Thank you.

Senator VITTER. I was going to, but, Senator, if you have any further questions——

Senator LAUTENBERG. Well, just—at what point is there a predictability, that's reasonable from evidence that you've seen in your studies, that says that there is no going back to the conditions that we've seen before—talking about the shellfish, talking about what's happening with wetlands as the flooding takes place and so forth, what happens to those bird populations or the fish populations that dwell in those areas. Is it expected that there's always going to be some replacement for those? I mean, are we—if we're going to be a hot world, is it likely that we're going to be able to sustain life as we know it? I mean, one thing we know is that there's going to be more carbon poured into our atmosphere than there is now. That's—one doesn't have to be a forecaster for that. Well, what's that going to do to us?

And I admire your patience, I must tell you, as you search the scientific routes for knowledge. But I'm an ordinary plain human being, and I worry about the things that I see in front of me, about things that change, temperatures changing, the—I mentioned the polar bears. There are other species that are under assault as a result of this. We see penguin populations. I've told you spent time in Antarctica, and went to the South Pole, and scientists who are working there are very worried about what's happening.

And, at some point, when do we extinguish the fire before it totally consumes the forest? And at what point do we work on these problems that we see in front of us to say there's enough out there to alarm us, to—for us to say, "Hey, we're going to find out more about the natural cycles that can be anticipated?" But we know something that we're doing that has affected it. There's a report by the National Academy of Sciences that say that the human influence on us is a—the changes observed—temperature is, in fact, rising. It's—the changes observed over the last several decades are likely mostly due to human activities. We can't rule out that some significant part of these changes are also a reflection of the natural variability—National Academy of Science, 2001. Do we dismiss that in the interest of research and say, "OK, that's there, but we've got to get on with it, with doing more research before we dampen the fire?"

Dr. MURAWSKI. Sir, I think most of the research that we're trying to do is to try to frame these sets of issues for people, as yourself, the people who make public policy, in terms of how we're going to

make adjustments or mitigation or adaptation to these issues. And we're trying to narrow the bounds of uncertainty, and to try to understand particularly the regional effects, which will play out in many of the examples that you talked about.

As to what we do about them, it's a much larger problem than scientists can actually deliver the information and the bounds of certainty, but this is in the public-policy arena.

Dr. ARMSTRONG. Sir, one of our——

Senator LAUTENBERG. Doctor?

Dr. ARMSTRONG.—responsibilities is—at USGS is—being the science wing of the Department of the Interior, is to provide science information to our land resource brethren at National Park Service, Bureau of Land Management, Fish and Wildlife Service, Bureau of Indian Affairs. And I will tell you that the problems that you've addressed today are real problems, and they are things that we are—the response of polar bears, of seals, of invasive species, of plants and other animals, especially in climate-sensitive areas, are things that we are currently addressing and looking into and trying to develop an understanding of the cause and effect. What causes a polar bear to lose weight, or what causes a seal population to migrate to other areas? We're looking at these things now.

And I would actually say to you that it would be irresponsible of us, as scientists, not to provide you the information you need and to give you our best professional judgment. But, in doing that, we need to show you, also, what degree of certainty and what kind of confidence level can we give you that information you need to make decisions with. And that's the thing that we're working on now, is trying to better understand those cause-and-effect processes.

Senator VITTER. Second panel.

Senator LAUTENBERG. Yes, OK. So—and I'll wrap up here—I just—would it be advisable for us to try to reduce deforestation of our wooded lands? Do they matter? Would it be wise for you folks to say, "Hey, listen, cut down on the amount of carbons that are released into the atmosphere"? We're—is that a good idea, or is that to be left for another day or another year, another century?

Dr. ARMSTRONG. I think it's appropriate for the policymakers and the resource managers to give you that information that they determine to be appropriate. At USGS, it's up to us to provide the science to those people that make those decisions.

Senator LAUTENBERG. Thank you.

Senator VITTER. Thank you all very much.

Dr. ARMSTRONG. Thank you.

Senator VITTER. And as the second panel is taking the witness table, I'll begin to introduce our three panelists who comprise the second panel.

First we'll hear from Dr. Syun–Ichi Akasofu, Director of the International Arctic Research Center in Fairbanks, Alaska. And we thank him, again, for traveling such a distance to be with us. We're also joined by Dr. Robert Corell, Senior Policy Fellow of the American Meteorological Society and affiliate of the Washington Advisory Group; and, also, Dr. Paul Reiter, Professor of the Institut Pasteur, in Paris, France. And we also thank him for traveling such a long distance.

And as soon as everyone is settled, we'll begin with Dr. Akasofu's testimony.

Thank you.

The CHAIRMAN. Could I introduce Dr. Akasofu to you?

Senator VITTER. Absolutely, Mr. Chairman.

The CHAIRMAN. I just think you should know that Dr. Akasofu conceived the idea of the Arctic Research Center and obtained the support of Japan and of Canada and the United States, and, to a certain extent, of Russia, for the activities that are conducted there. This is an international center. Substantial Japanese funds have gone into that, as well as others. And I think we owe him a debt of gratitude for what he's done, dedicated a substantial portion of his life to this one area of science.

Senator VITTER. Absolutely. I agree completely.

Doctor?

STATEMENT OF DR. SYUN–ICHI AKASOFU, DIRECTOR, INTERNATIONAL ARCTIC RESEARCH CENTER, UNIVERSITY OF ALASKA FAIRBANKS

Dr. AKASOFU. Mr. Chairman and members of the Subcommittee, I really appreciate, thank you for providing me with the opportunity to testify at this important hearing today.

The CHAIRMAN. Syun, pull the mike toward you, will you? Pull it right——

Dr. AKASOFU. Let's see. As Senator Stevens says, that I am the Director of the International Arctic Research Center. Senator Stevens helped us to establish the center. We have been working on—specifically on climate change.

I would like to summarize my testimony. And the most—the prominent warming in the world was taking place in the continental Arctic during the last half of the last century. So, it—the three times more than the rest of the world. So, the warming signals are the largest, so we like to concentrate on that to try to understand it.

The—in the continental Arctic, we have—because of warming, we have degradation of permafrost—forests and so on, and many other phenomena.

However, we have at least two firm scientific indicators that show it is incorrect to conclude that this warming in the continental Arctic is due entirely to the greenhouse effect caused by man. The first indicator is that most advanced 14 IPCC global climate models, which includes the best scientific knowledge of the greenhouse effect, cannot reproduce the warming of the continental Arctic during last half of the last century. The IPCC cannot reproduce. This is what we call hindcasting. We are using last 50 years of data, last IPCC—best IPCC group to reproduce that. And so, we think it's best scientific test of the greenhouse hypothesis.

In the scientific methodology, what we do is we make observation—in this case, global warming. Then we hypothesize the causes of the warming, the second step. And the last step is to verify the hypothesis. If necessary, using the supercomputer. And if computer simulation and observation agree, then the observations and the—our understanding becomes scientific fact.

But if there is—computer cannot reproduce what we observe, then the hypothesis has to be disproved. And—but you still insist that—someone still insists that greenhouse effects is going, then that belongs to the area of what we call science fiction, because the science fiction you don't have to rely on any science.

So, then—so, the first test is, we cannot reproduce the continental warming, which is—as the largest, most prominent feature of the warming today. The second indicator is that geographic pattern of the warming in the Arctic has been drastically changing during the last—in recent years. Strong continental Arctic warming trend is no longer evident during the last two decades.

If the warming trend during the last half of the last century were entirely due to the greenhouse effect, the past geographic pattern of the warming should intensify, but this is not the case. Various warming and cooling of similar magnitudes has continuously occurred at different locations and different times during the last hundred years. So, it's natural to conclude that such a trend will continue, as Dr. Armstrong said, the—both natural and manmade component.

In addition, long-term record of the glaciers and the sea ice show that they have been—those glaciers and the sea ice have been receding around about 1,800, well before the CO_2 effects became serious. We have some evidence that the present recession of sea ice in the Arctic Ocean is due partly to the intrusion of warm North Atlantic water, which is caused by what we call North Atlantic oscillation, a natural phenomenon, like El Niño. So, this warm water is now flowing around the Siberian coast and approaching Alaska.

Also, it's very important to notice that our sun is changing. The solar physicists have been working on this for years, and they've found that very important solar output is changing.

So, it is my conclusion that it is urgent to identify both natural and manmade components of the present warming. So, results that will be—of—like house-fire example that Senator mentioned, we are not sure if the house is really on fire. And to put the water where it would make water damage may be more damaging.

That's my testimony.

[The prepared statement of Dr. Akasofu follows:]

PREPARED STATEMENT OF DR. SYUN-ICHI AKASOFU, DIRECTOR, INTERNATIONAL ARCTIC RESEARCH CENTER, UNIVERSITY OF ALASKA FAIRBANKS

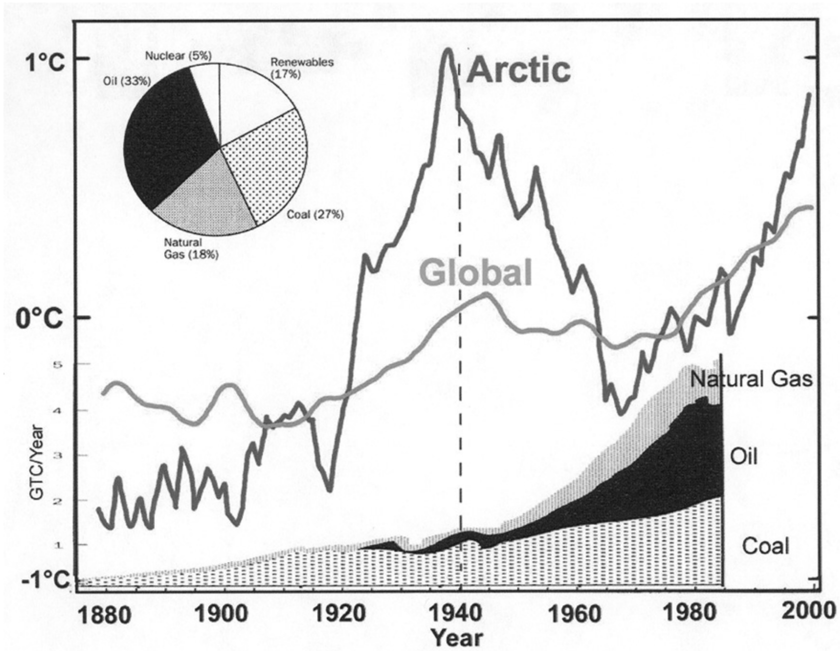
Thank you for providing me with the opportunity to testify at this important hearing today.

In order to avoid any misunderstanding, I would like to state at the outset that it is in the best interests of mankind to reduce the rate of increase of our release of CO_2. My talk is about how much this future reduction should be. For this purpose, I would like to demonstrate that:

1. Prominent climate change is in progress in the Arctic, compared with the rest of the world. However,
2. arctic climate change consists of *both* natural change and the greenhouse effect, and thus
3. it is incorrect to conclude that the present warming in the Arctic is due entirely to the greenhouse effect caused by man.
4. Therefore, it is important to find out the contribution of both natural and manmade components to the present climate change in the Arctic.

The first statement can be illustrated in Figure 1. The range of temperature change along the coastline of the Arctic Ocean is much greater than that of the glob-

al average. Please note a rapid increase from 1920 to 1940, a decrease from 1940 to 1970, and a rapid increase again from 1970 on.

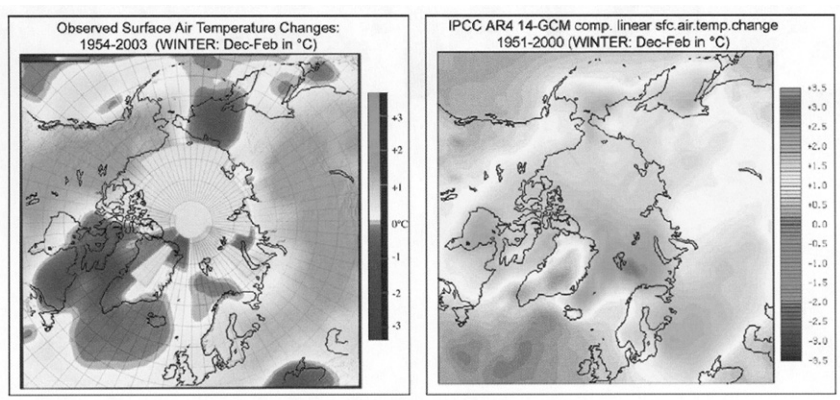


(Figure 1)

(IPCC and I. Polyakov)

It is also important to note that both the Arctic and global temperatures began to *decrease* in about 1940, when our release of greenhouse gases began to *increase* rapidly. Thus, the increase-decrease between 1920 and 1970 must be natural change. One important task we have is to find out the nature of the warming periods from 1920 to 1940, and from 1970 to the present time. An important question is whether or not the present rise will continue or whether future temperatures will decrease, as was the case during 1940 to 1970.

Let us examine where in the Arctic temperature changes occurred during the last half of the last century. The left-hand side of Figure 2 shows clearly that the most prominent warming was in the continental Arctic (Siberia, Alaska, and Canada), except in Greenland, where it cooled.

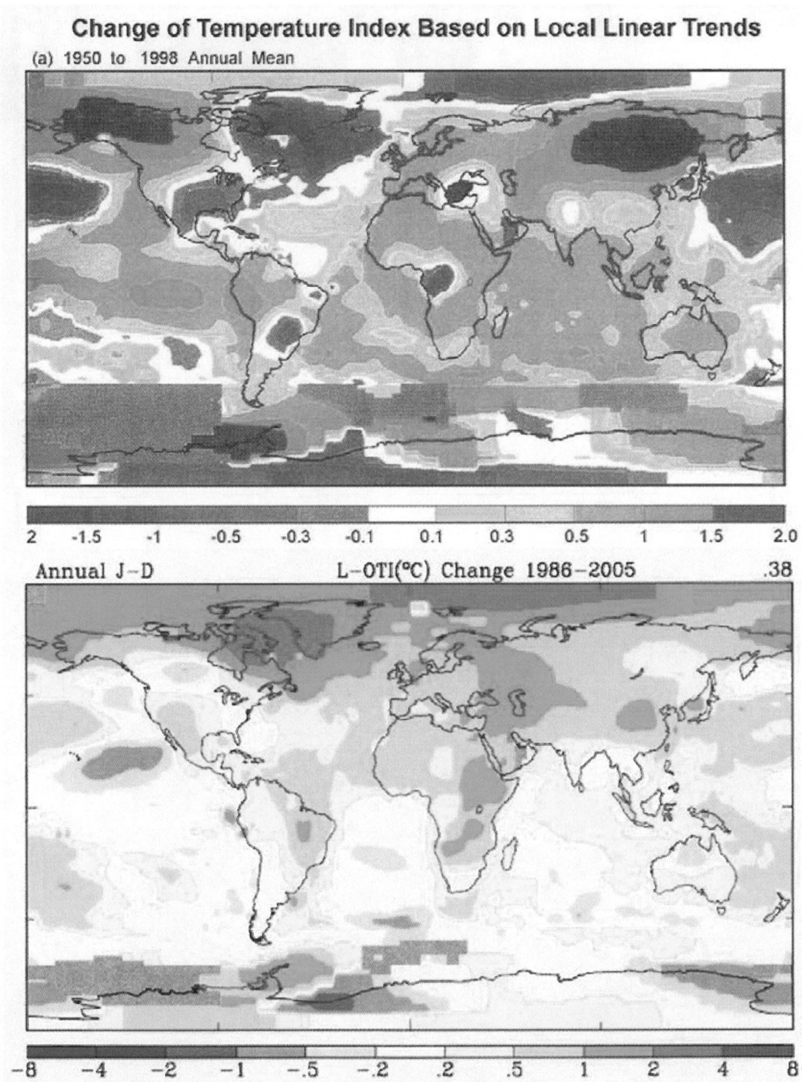


(Figure 2)

(ACIA Report) (IPCC-GCM – W. Chapman)

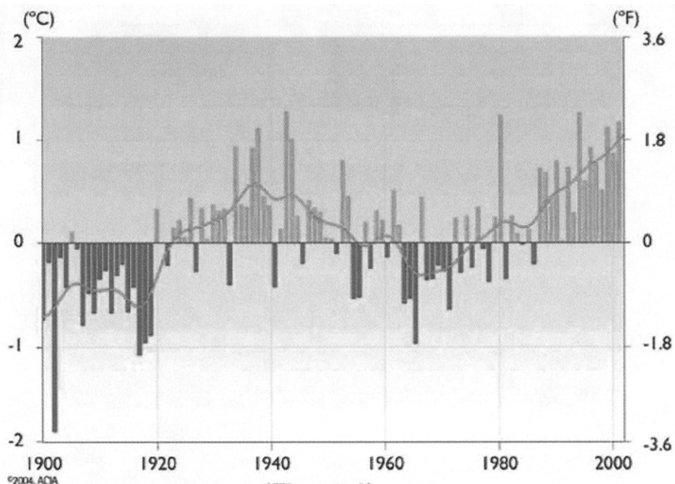
The IPCC Arctic Group, consisting of 14 Global Climate Modeling (GCM) teams headed by V. Kattsov, tried to reproduce the temperature change for about the same time period on their models. Their results are shown in the right-hand side of Figure 2. The simulation result bears no resemblance to the observed, real temperatures in the continental Arctic. If the simulation were reasonably accurate, the results should be similar. This is the most quantitative test to date to examine if the continental arctic warming during the last half of the last century was caused by the manmade greenhouse effect. This comparison shows clearly that much of the prominent warming in the continental Arctic after 1970 was not caused by the human-induced greenhouse effect.

If, in fact, the continental warming indicated in the right-hand side of Figure 2 were caused by the greenhouse effect, this trend should have been intensified during the last few decades. However, that is not the case. The continental warming in the upper part of Figure 3 (which is similar to the left-hand side of Figure 2) is absent during the last 20 years (the lower part of Figure 3). Thus, the continuous increase of the warming is not taking place any more. Instead, intense warming is now in progress in Greenland, which experienced cooling in the recent past.



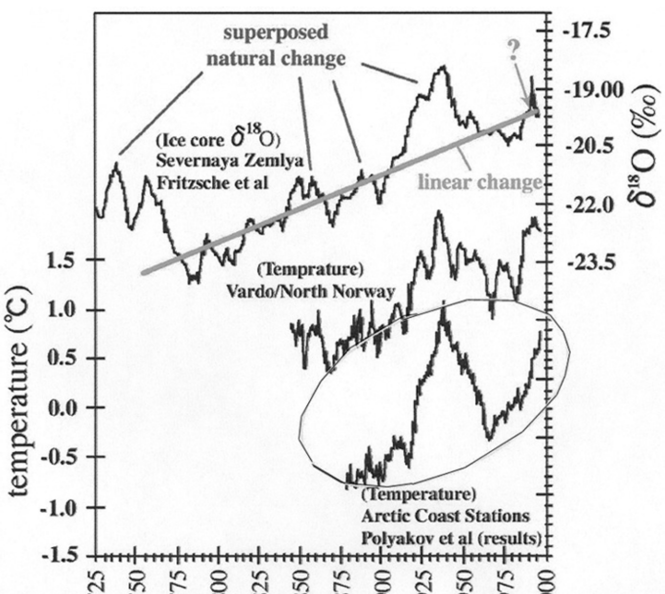
(Figure 3)
(J. Hansen)

Further, let us examine temperature changes during the last century. Figure 4 is similar to Figure 1, except it includes the Subarctic, and the zero line represents the average value of the last century. One can see that warming and cooling continuously occurred during the last century. Thus, it is not difficult to infer that the rise after 1970 is not entirely due to the manmade greenhouse effect.



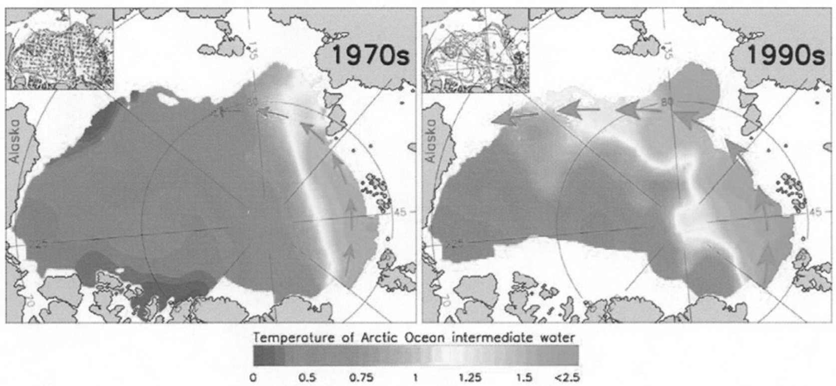
(Figure 4)
(ACIA Report)

Fortunately, we now have longer-period ice core data from an island in the Arctic Ocean. It is shown at the top of Figure 5. The bottom trace is the reproduction of Figure 1, and the middle one is the temperature record in northern Norway. All three traces show similar change from 1900. In addition, the ice core data show clearly that there are both linear and irregular changes from 1725, well before the effects of the Industrial Revolution became serious. Thus, it is clear that the last rise since 1970 is not entirely due to the greenhouse effect.



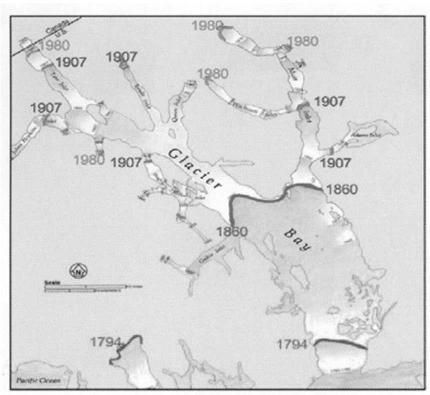
(Figure 5)
(D. Fritzsche, et al. and I. Polyakov)

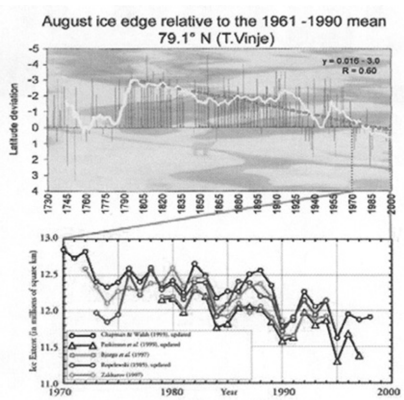
It is likely that part of the rises and falls of temperature in 1920–1970 can be identified as what is called a “multi-decadal change.” One possible cause of this multi-decadal change is the changing intensity of the intruding warm North Atlantic water into the Arctic Ocean (Figure 6), which is associated with a natural phenomenon called the North Atlantic Oscillation (NAO). At the present, the warm water is flowing toward the Alaska coast. Studying and tracking this warm-water pulse, which may be a natural reason for some loss of sea ice, is one of the major projects of the International Arctic Research Center (IARC), conducted with the help of the Russian Icebreaker Kapitan Dranitsyn.



(Figure 6)
(I. Polyakov)

In recent years, there have been a large number of reports that both glaciers and sea ice in the Arctic Ocean have been receding. However, longer-term records show that such phenomena have been in progress continuously since 1800 or earlier (Figures 7a and 7b), and are not phenomena that began after 1970. Glaciers in the Glacier Bay National Park began to recede at least by the time Captain Vancouver passed by in 1794, and the ice edge in the Norwegian Sea began to recede in about 1800.





(Figure 7a)
(S.D. Wiley)

(Figure 7b)
(T. Vinje)

These data show clearly that it is dangerous to infer causes of climate change using only data that cover the last 40 years or so. In recent years, there have been a large number of excellent papers that describe arctic climate change since about 1970. This is because high quality satellite data became available only after 1970. Fortuitously, this period also coincides with the beginning of temperature rise dur-

ing the last several decades. Thus, all such reports on scientific results are naturally related to the topic of rising temperatures.

Although I respect the authors of those papers, I cringe somewhat when the papers are consumed immediately by the media and then the public. Unfortunately, members of the press often champion these papers as showing examples of the greenhouse effect, which tends to sensationalize the results. Thus, the general public often interprets the results to mean that all climate change in the Arctic must be caused by the manmade greenhouse effect.

These scientific reports should be treated like any other scientific papers in professional journals. Any significant conclusions should be scrutinized by the scientific community before they become material for public consumption. This requires a certain period of time. Although I am happy to have the present great public interest in our research topic of global warming, such instant reporting of results for relatively short time periods can cause much confusion in the minds of the public. It is not as simple as stating that "warming melts ice."

Unfortunately, data gathering for periods before the 1970s is much more difficult and much more time consuming than obtaining satellite data. Today, many climatologists tend to avoid dealing with the topic of climate change before the 1970s. Further, those data may not be of the quality researchers desire, and some researchers tend to discredit results based on data before 1970, which is a good excuse to avoid longer-period data. Therefore, these days there are only a handful of researchers who deal with climate changes over the last century in great detail. In fact, it is alarming that only a few researchers in the world are studying the sharp increase of temperature that occurred from about 1920 to 1940 and the sharp decrease that occurred from 1940 to 1970.

Our understanding of the change between 1920 and 1970 is crucial for interpreting the rapid rise from 1970 on and also for future predictions, because the change between 1920 and 1940 is most likely a natural one. If computer modeling were adjusted to reproduce the present rise, assuming that the present rise is due entirely to the greenhouse effect, its prediction for future years will not be accurate.

We tend to forget that some climatologists, who were studying the temperature decrease from 1940 to 1970, warned the public that a new Ice Age was just around the corner. Apparently, we have not learned the lesson of the "new Ice Age mistake": short-period data do not tell the whole story.

In conclusion, the nature of the climate change after 1970 should be a matter of great debate. It should not be assumed that this short period of warming is entirely due to the greenhouse effect caused by the actions of man. The prediction of future trends depends greatly on the understanding of the nature of the rise after 1970.

Thank you again for the opportunity to present this testimony today, and thank you for your interest in this important issue. Please feel free to contact me if you have any additional questions.

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Senator VITTER. Thank you very much, Doctor.
Dr. Corell, welcome.

STATEMENT OF DR. ROBERT W. CORELL, SENIOR FELLOW, AMERICAN METEOROLOGICAL SOCIETY; AFFILIATE, WASHINGTON ADVISORY GROUP; CHAIR, ARCTIC CLIMATE IMPACT ASSESSMENT

Dr. CORELL. Thank you, and good afternoon, Mr. Chairman, Senator Stevens, Senator Lautenberg, and all gathered here. I really appreciate the opportunity to join you in this hearing today.

I'd like to put some context for our discussion, because there have been significant shifts of the climate in our planet, with substantial changes and increases in temperature, particularly during the last 150 years or so, as reported by Professor Moberg and many others who have documented, as depicted here, the picture over the last 2,000 years, the so-called hockey stick. And, as you can see, the instrumental record is clear that things are happening in the last 150 years that certainly are unparalleled in the last 2,000 years.

The IPCC third report concludes that while some of the fluctuations we see—and you can see them here, they are natural in character—come from natural variability, it is clear now, to the IPCC any ways, that human influences are responsible for most of the roughly 1 degree Fahrenheit global warming that has occurred over the 20th century, and that the IPCC predicts and suggests that those temperatures, over the next hundred years, may reach as much as 5 to 9 degrees Fahrenheit.

First let me say a word or two about the ocean and the marine setting. A simple and important message, the oceans control the timing and magnitude of the changes of the climate system, and do so over decadal timescales. Further, the—any imbalance of incoming radiation—and we do have an imbalance at the moment—90 percent of that energy ends up in the ocean. The 10 percent is what we hear about, reducing sea ice, melting glaciers, warming the atmosphere. So, the oceans are the dominant player in the situation.

Professor and Dr. Hansen and his group in Columbia have done an extensive study of the last 10 years of this increased warming of the ocean, and have concluded that the Earth is now absorbing about .85, plus or minus a small amount, watts per square meter. That number doesn't mean anything, but it does mean the following, and that is, already stored in the ocean is another .6 degrees, or roughly 1 degree Fahrenheit, of warming of the planet without any further increase of greenhouse gases in the atmosphere. So, it's like a supertanker. It stores it, and it takes a long time for it to play out.

And, in that regard, Mr. Chairman, in answer to your question, at least when we're combining warming that's due to both natural and anthropogenic factors, it's clear that there is a lead-lag relationship, that, as CO_2 goes up and the warming takes place of the ocean, it will take a somewhat longer time for that to be expressed as a warming of the overall atmosphere.

This oceanic warming has a wide range of impacts, both physically and biologically. The first is that there's a long-term effect on sea level, which I'll come back to. As the heat is propagated down-

ward into the ocean, we're only heating the upper few hundred meters already, and we have 4,000 meters to go. And as that heat propagates down, the oceans expand, and sea level will continue to rise. And I should note that most of the sea-level rise that we've experienced to date has come from this thermal expansion of the ocean, and not from land-based ice melting.

As Dr. Murawski has indicated, there certainly is a clear impact on fisheries, marine mammals, sea birds, and other marine life, and it will have a significant change in the future. The shift in fisheries have already been observed, and will continue to occur as both oceanic temperatures and currents shift. Marine mammals, including walrus, sea whale, seals, and polar bears, are already being impacted, as Senator Lautenberg aptly pointed out.

While the ocean, as a whole, can store vast amounts of CO_2, it's not very well mixed, and much of that absorption of CO_2 builds up near the surface. And this has the effect of altering the oceanic chemistry and resulting in increased acidity of the ocean, which has already been noted by previous testimony.

What I'd like to note here is that as the CO_2 in the atmosphere increases from our present level, about 380 or so parts per million, up toward the 6–700 region, laboratory experiments on the calcification process of plankton strongly indicate that these animals—or these plants at the lower end of the food chain will have a very difficult time forming. And you can see the difference between the lower left and the lower right. So, the acidification will play a profound role, and the impact in the whole life chain in the oceanic region.

The extent of summer sea ice has already been reduced by about 20 percent in the past 20 years or so, and the Northern Sea route is already opening up along the Russian coast, which will, in the end, open up seaways that are about 45 percent closer in time between the two markets of the Far East and Europe.

What are some of the impacts in the terrestrial biosphere? Changes in CO_2 itself will have an effect on the terrestrial biosphere. As a result, higher concentrations will lead to greater carbon uptake by plants. Storage in the plant material will increase as long as the soils have adequate nutrients, such as nitrogen, to support it. Food production will likely increase in the short term, or at least until concentration gets sufficiently high that—where other factors will start limiting their productivity.

So, for natural systems in forests and grasslands, the situation is likely to be even more problematic than it is in the agricultural region. Each ecosystem has a preferred set of conditions, relationships between each element in the system. And as the climate shifts some range—some ecosystem elements can move slowly, some move fastly. And, therefore, the out-year composition of those ecosystems is likely to be quite different than they are now.

The temperature increases that we've already experienced in Alaska since 1970 in the Kenai peninsula have indicated how disastrous those modest temperature increases can have, because the over-wintering of the spark—the spruce bark beetle has already led to sudden and really widespread loss of the white spruce forests.

Finally, the projected increase in frequency of droughts, wildfires, floods, and other extremes, such as hurricanes, are the kind of

thing that we can expect to have impact not only on our ecosystems, but on our society as a whole. And because these projected changes are evident in the frequency of the events, the timing and the intensity, and the localization of some of the participation, all sorts of challenges lie ahead, some of which we have ability to see, others of which will require continued research, and one of the most important of which is the status of freshwater reserves around the planet.

Now, in the Arctic, the melting of snow cover and the river-ice permafrost combined with the loss of sea ice has had, and will continue to have, a really profound effect on wildlife, particularly on its movement across the regions. Warmer species—warming conditions have already resulted in new species. If you go to the Inuits, in the north of Canada, the word "robin" doesn't exist in their vocabulary or in their language, and robins are now prolific in those regions.

As a result of these kinds of changes across the U.S. and also around the world, conditions such as heat waves, drought conditions, will be more favorable to propagate wildfires, as Alaska has experienced one of the most incredible wildfires a couple of years ago, of 600—6.5 million acres destroyed in one setting.

On the other side of the precipitation question, there is going to be more intense——

Senator VITTER. Doctor, if you could start to sum up, I want to——

Dr. CORELL. I would—surely. There will be more intense rainfall, which will result in more flooding.

I want to say a word or two about Greenland. The ice melting there is pretty dramatic, as you can see in these images. And there has been a melt of about 20 percent increase just in the past 25 years, and last year the melt region was the largest in recorded history.

Sea-level rise will have an impact, such as 1 meter of sea-level rise on Florida, as indicated in this diagram here; and elsewhere around the planet, even more profound implications.

I was just recently in Alaska to visit Shishmaref, which is a very important village to the Alaskans, and the picture in the lower right—lower left-hand corner was taken only a couple of weeks ago. It resulted from a storm last fall, that the sea ice used to protect that shoreline, and the sea ice is no longer there to do so. And, as a consequence, the village is going to have to move, at very costly levels.

So, the Arctic now is really experiencing some of the most rapid and severe changes, and it's going to be that way in the future.

Let me just summarize by saying that the Arctic is one of the most important regions to note what's happening. As Senator Stevens said, it's the bellwether, it's the place in which we will see the most change most rapidly, and it is a part of our country.

And while it's clear to me that global change is here, we've got a major task ahead of us. I urge all of us to join together in giving this serious attention to look at assessments as a vehicle by which science can communicate its knowledge at global, regional, and national levels to policymakers like yourself.

Thank you for your attention and your time.

[The prepared statement of Dr. Corell follows:]

PREPARED STATEMENT OF DR. ROBERT W. CORELL,[1] SENIOR FELLOW, AMERICAN METEOROLOGICAL SOCIETY; AFFILIATE, WASHINGTON ADVISORY GROUP; CHAIR, ARCTIC CLIMATE IMPACT ASSESSMENT

Introduction

Mr. Chairman, Members of the Subcommittee, and all gathered here today, I thank you for the opportunity to participate in today's hearing on the "*Projected and Past Effects of Climate Change: A Focus on Marine and Terrestrial Systems.*" I am honored to join you to explain the science that underpins understanding of the past and projected effects of climate change, especially in terms of the impacts on marine and terrestrial systems in North America, across the Arctic region, and around the world.

In offering these perspectives, I will be drawing primarily from the findings of major scientific assessments, a number of which I have been involved with, because these assessments very thoughtfully draw together the collective findings of the scientific community. These assessments deserve very high and special consideration because their credibility has been well established as a result of their extensive open review processes, which have helped to carefully hone their findings.

At the national level, I will be drawing upon the results of the U.S. National Assessment that was completed 5 years ago.[2] In my role from 1990–1999 as chair of the Subcommittee on Global Change Research that directed the U.S. Global Change Research Program, I was instrumental in the organization of this assessment, and after I left government service I served on the National Assessment Synthesis Team that summarized the assessment's findings. In describing potential consequences for the Arctic, I will be drawing mainly from the results of the Arctic Climate Impact Assessment (ACIA), which was completed in 2004,[3] having been established and charged to conduct the assessment by the Arctic Council[4] and the International Arctic Sciences Committee.[5] For ACIA, I served as chair, leading an international team of over 300 scientists, other experts, and elders and other insightful indigenous residents of the Arctic region in preparing a comprehensive analysis of the impacts and consequences of climate variability and changes across the Arctic region. At the international level, I will be drawing mainly from the results of the Intergovernmental Panel on Climate Change (IPCC), which I was instrumental in helping to conceive in the late 1980s in my role as Assistant Director for Geosciences at the National Science Foundation (NSF) from 1987–1999. The IPCC's members are the nations of the world and the periodic assessments that they commission represent the collective evaluation of scientific understanding by the international scientific community. That the IPCC's assessments of 1990, 1995, and 2001 have been unanimously accepted by the world's community of nations gives a strong indication of the widespread agreement that exists regarding the major finding that human-induced climate change is already influencing the climate and the environment and that much larger changes lie ahead.[6] For more detailed information and scientific citations on most of my points, reference should be made to the cited assessments. In areas where the pace of research has been especially rapid or significant in recent years, however, I will also be drawing upon the results of more recent scientific articles, which I will specifically reference.

Context for Today's Hearing

The IPCC's Third Assessment Report[7] summarized the peer-reviewed scientific evidence that human activities, in particular the ongoing emissions of carbon dioxide (CO_2) and other greenhouse gases to the atmosphere resulting primarily from the combustion of coal, oil, and natural gas, are causing the Earth's climate to warm more rapidly and persistently than at any time since the beginning of civilization. While some of the fluctuations are likely a result of natural factors (e.g., variations in solar irradiance and major volcanic eruptions), the IPCC evaluation concluded that the strength and patterns of these change makes clear that human influences are responsible for most of the roughly 0.6°C (1°F) warming during the 20th century. In particular, despite the cooling influence of the 20th century's largest volcanic eruption in 1991, the fifteen warmest years in the instrumental temperature record available since 1860 have all occurred in the last 25 years,[8] and comparison with paleoclimatic reconstructions[9] of temperatures over the last two thousand years indicates that recent warmth is unprecedented, at least for the Northern Hemisphere where paleoclimatic data are most available.[10] In addition to the warming of the surface, which has been particularly strong in the Arctic,[11] warming is also evident in ocean temperatures (causing some of the sea level rise), below

ground temperatures, and temperatures well up in the troposphere.[12] Other evidence of climate change includes diminishing sea ice and snow cover in the Northern Hemisphere, melting back of mountain glaciers in the tropics and in most other locations around the world, and an increasing tendency for precipitation to occur in relatively heavy amounts.

For the future, IPCC projects that significantly greater warming lies ahead. Considering a wide range of possible scenarios for how human activities (e.g., changes in population, technological development, energy use and supply, economic development, and international cooperation) are likely to alter atmospheric composition during the 21st century, the IPCC projects a further increase in average annual surface air temperature around the globe of roughly 1–2°C (1.8–3.6°F) from 1990 to 2050 and a further 1–2.5°C (1.8–4.5°F) by 2100, bringing the projection for total human influence from the start of the Industrial Revolution to 2100 to roughly 2.5–5°C (about 4.5–9°F).[13] As is the case for the warming over the 20th century, future changes are expected to be greater over land than over the ocean, greater in mid- to high latitudes than in low latitudes, and, except where regions really dry out, greater during the winter than during the summer and greater during nighttime than daytime. As will be explained more fully in discussing likely impacts, many other aspects of the world's weather and climate will also be affected.

That such changes in the climate will occur as a result of human activities is no longer scientifically controversial. During the rest of my testimony, I will discuss what the likely consequences of the changes in atmospheric composition and climate are likely to be for the environment, focusing on three specific domains:

- Oceans and marine systems;
- The terrestrial biosphere; and
- The interface between the marine and terrestrial environments.

My discussion will focus on the links between climate change and these systems. It is important to recognize, however, that a number of additional stresses are affecting each of these environments, including air pollution, nitrogen deposition, toxics such as mercury, unsustainable extraction of resources, over-fishing, nutrient-induced eutrophication, depletion of stratospheric ozone and UV enhancement, etc. Climate change is thus only one aspect of global environmental change, although a continuously accumulating one that over time will have very large impacts, and for a full evaluation of likely environmental consequences for both marine and terrestrial environments, comprehensive research and assessment efforts are essential.

Interactions and Impacts Linking Climate Change and the Ocean and Marine Environment

Oceans cover about 70 percent of the Earth's surface. Because of their large heat capacity, the oceans moderate climatic swings by supplying heat to the atmosphere and adjacent continents during the winter and, because they warm relatively slowly during the summer, are the source of cooling sea breezes during times of peak solar radiation. Much of the heat absorbed by the oceans goes into evaporating water, providing the moisture that supplies vital precipitation for land areas via the monsoons and tropical and extratropical storms. These rains and associated geochemical interactions help to cleanse the atmosphere of pollution. In addition, oceans support a wide diversity of biological life that supplies fish, birds, marine mammals and other species higher in the food chain, and supports the fisheries that in turn provide substantial food for humans.

While the oceans seem so large that it is hard to imagine that human activities could affect them, records over geological time and observations of recent changes make clear that both the physical and biological systems in the ocean are quite sensitive to changes, and, indeed, are being affected. The very human activities that are causing the climate to change are becoming the major influence on the oceans.

First, the oceans affect atmospheric chemistry. In their natural state, cold waters forced to the surface by wind patterns in low latitudes release large amounts of CO_2 to the atmosphere as they warm. Before humans started altering the carbon cycle, roughly the same amount was taken up in mid- to high latitude ocean areas as the ocean waters cooled and marine organisms grew, died and sank to the ocean depths. With this balance, which was modified somewhat during glacial periods when the oceans were colder, the atmospheric CO_2 concentration has been held in the range of about 180 to 300 ppmv[14] for the past several million years. As human activities began to emit large amounts of CO_2 as a result of combustion of coal, oil, and natural gas, the atmospheric concentration has been driven higher because the oceans and living biosphere cannot absorb it all. On time scales of years to centuries, the oceans take up about a third of the emitted amount, limiting the atmospheric build-up and thus moderating the pace of climate change.

While the oceans as a whole can hold vast amounts of dissolved CO_2, the oceans are not well mixed vertically, and so most of the added CO_2 builds up in the near surface layer. This has the effect of altering oceanic chemistry, most importantly by making the ocean more acidic.[15] Increasing oceanic acidity has a range of effects, but the most important is that it makes it chemically more difficult for marine organisms to form shells. For corals, the rise in the CO_2 concentration from its preindustrial value of about 280 ppmv to its present value of 380 ppmv has already caused a significant shrinkage in the regions most favorable for reef-forming, and by 2050, virtually all of the most favorable regions in the world will have disappeared, simply due to the rise in the CO_2 concentration.[16]

Adding in the sensitivity of corals to warmer ocean waters (the "coral bleaching" effect), the prospect for more powerful storms and wave conditions, the increasing threats from coastal runoff and fish-harvesting, and other stresses, the prospects for many of the world's reefs are very problematic. While the potential impacts on coral are of most immediate concern, impacts on other shell-forming organisms are also likely to become significant over coming decades, particularly as the CO_2 level approaches 750 ppmv.[17]

As the rising concentrations of CO_2 and other greenhouse gases have trapped more infrared radiation, making it more difficult for the Earth's surface to cool, most of the additional heat has been taken up by the oceans because they are capable of mixing it through the upper hundred meters (yards) or so of ocean depth. Surveys of ocean temperature give a clear indication that the ocean's upper layers are warming;[18] indeed, the warming that is being observed is in good agreement with climate model simulations of how the oceans are being projected to warm as a results of the changes in atmospheric composition.[19]

This oceanic heating is having a wide range of both physical and biologically important impacts. Because the oceans are able to mix the heat downward, they are able to slow the warming of the atmosphere, which is beneficial, but it also means that we are not experiencing the full extent of warming to which past emissions of CO_2 have committed the world. Experiments with climate models indicate, for example, that the world would be committed to further warming of about 0.5°C (almost 1°F) even if global emissions of CO_2 were to be quickly cut to near zero.

Warming of the oceans also makes more energy available to the atmosphere if just the right conditions prevail. For example, warm ocean waters provide the energy needed to intensify tropical cyclones (*i.e.,* hurricanes and typhoons), and indeed, recent studies[20] are finding that increasing sea surface temperatures are leading to an increasing proportion of tropical cyclones to be in the most powerful and destructive categories (more on the consequences of more powerful tropical cyclones in the section dealing with the ocean-land interface). While there has been significant debate recently about whether the available record provides a definitive indication of this linkage, a paper in press in the *Bulletin of the American Meteorological Society,* of which I am a co-author, finds that there are many reasons to suggest that there is indeed a strong linkage and that it may well be limitations in our detective work that are the problem.[21] If this is indeed the case, and it seems quite likely, then the world faces a situation where the storm season is becoming longer, storms may well last longer, and the likelihood of relatively intense storms is increasing, likely leading to greater and greater destruction and loss of life unless our adaptive efforts[22] are significantly increased.

Climate change also has the potential to influence the pattern and character of the normal year-to-year fluctuations of the climate. For the Pacific region and then for much of the U.S., the natural variation of the El Niño-Southern Oscillation (ENSO) is of critical importance, variously causing El Niño and La Niña events (*i.e.,* unusual warming or cooling in the eastern tropical Pacific, respectively) that redirect the Northern Hemisphere jet stream, thereby creating either quite wet or quite dry winter conditions across various parts of the U.S. (e.g., this year, the ocean conditions are causing the U.S. West Coast to be inundated with very large amounts of rain). Research to date only hints at how ENSO may be affected, with some indication that the overall conditions may become more El Niño-like with more intense El Niño events (meaning, for example, more winter precipitation for California, increasing flooding potential in the spring and increasing the stock of burnable vegetation). However, there remains significant disagreement among model results and this area is, therefore, being investigated intensively by various research groups.

Changes in atmospheric winds and weather (a result of the warming) and increasing ocean temperatures (which also feed back to affect the weather) also lead to changes in ocean currents. Under normal conditions, warm ocean waters are pulled poleward to replace cold waters that sink to the ocean depths in high latitudes. As these waters are pulled poleward, for example in the Gulf Stream, heat is given off that tends to keep Europe relatively warm in winter, given its latitude. As climate

change prevents ocean waters in high latitudes from cooling as much, the rate of sinking waters declines, and so less warm water is pulled poleward, providing less winter heat. While this slows the human-induced warming rate in Europe, it leaves that heat in lower latitudes, causing those regions to be warmer and even more moisture to evaporate, moisture that is likely to result in more intense rainfall events. Slowing the generation of oceanic deep water also slows the transport of dissolved CO_2 into the deep ocean, releasing somewhat the oceanic brake on the pace of global warming.

Fisheries, marine mammals, seabirds, and other marine life will all be significantly affected by these changes. Both the increasing temperature and freshening of upper ocean waters in some regions by increased precipitation will tend to increase stratification of the upper ocean, affecting the vertical distribution and productivity of biological activity.[23] Shifts in fisheries will occur (and some changes are already being observed) as ocean temperatures shift and changes in abundance will occur as the amounts of upwelling nutrients and associated biological activity are reduced. The retreat of sea ice will also lead to changes in fisheries, as the ice edge is normally a very productive site as a result of the release of nutrients from the melting ice and the protection from intense waves provided by the ice itself. Marine mammals, including walrus, seals, and polar bears, depend on the presence of sea ice to raise their young and to hunt for food, and the retreat of ice is already having a significant impact.[24] The shifts in ocean conditions, both of sea ice and of biological activity, are also starting to have effects on sea birds, which are also facing increasing competitive pressures from birds that normally are shifting northward as warming increases.

An added result of sea ice retreat will be the potential for greater access by ships. The melting back of sea ice is already near to opening the Northern Sea Route that would connect the Atlantic and Pacific Oceans via open water north of Eurasia. Not only would such a route cut shipping time significantly, but the route will also increase seasonal access to arctic resources, both below coastal waters and on land (although, perversely, the summer melting of the permafrost will make transport over land much more difficult). Already the Northwest Passage is becoming navigable for icebreakers and in the decades ahead greater access should be possible. Environmentally, such access will greatly increase the risk of contamination from spills and other pollution, and there is virtually no experience or effective approach for cleaning up such spills. Politically, the increased access is already raising questions of sovereignty, ownership of coastal zone resources, and rights to the shifting fisheries that will result. The identification of such issues as part of the Arctic Climate Impact Assessment formed the basis of the policy guidance document that was prepared by the Arctic nations as a framework for future discussions.[25]

Overall, human-induced climate change is thus already having significant effects on the ocean, the weather systems that the ocean generates, and on the biological systems that are dependent on its resources. Adding on the impacts of sea level rise on the coastal environment, which is treated below, the global oceanic environment on which we all depend is already screaming, at least in a figurative sense, for actions to greatly slow the pace of change, especially as roughly an equal amount of change as has already occurred is almost certain to result as a consequence of past human activities.

Interactions and Impacts Linking Climate Change and the Terrestrial Environment

Changes in both the CO_2 concentration itself and in the climate will affect terrestrial systems. Because CO_2 is needed by plants to grow, the increase in its concentration will, as a whole, enhance plant growth and allow the stomata (pore openings) on the undersides of leaves to open less, allowing less harmful air pollution in and less moisture out, thereby improving the overall health and water use efficiency of plants. As a general result, the higher CO_2 concentration will thus lead to greater carbon uptake and enhanced storage as plant material and in soils as long as nutrients and sufficient soil moisture are available. Recent studies suggest that the CO_2 fertilization effect will be limited by tropospheric ozone concentrations[26] as well as the availability of nitrogen in ecosystems.[27]

However, different plants respond quite differently. Under conditions with adequate moisture and nutrients, many types of crops (key exceptions are maize, millet, sorghum, and sugar cane) respond quite strongly to the increase in the CO_2 concentration, but then so too do many weedy plants, necessitating additional control measures. Assuming that farmers can overcome problems with weeds and increased occurrence of pests and that moisture amounts are sufficient, the per acre yield of many food crops is likely to increase by tens of percent.[28] It is for this reason that the IPCC and other assessments suggest that overall global food production will in-

crease, at least until the CO_2 concentration gets much higher when the effect can saturate or even changeover (*i.e.,* become essentially toxic). Simple economic analysis would then suggest that with more agricultural production, food prices will drop and that there will be sufficient food, at least for those who can afford it, providing a net economic benefit to society. However, the situation in the real world is a good bit more complex. In the U.S., for example, overproduction currently leads to the need for subsidies as a result of overproduction, and so an increase in productivity and a decrease in commodity prices may well lead to calls for larger subsidies. With the climate also changing, there will also be a constant need to adjust seed strains to ensure optimal productivity,[29] creating greater needs for support of crop development programs at, for example, the land grant universities.

In addition, while productivity will go up in both good and marginal farming areas, the increase will be greater in absolute amount in the better farming areas, and so the economics of farming in marginal areas is likely to worsen, leading potentially to the abandonment of farming in such areas unless a switch can be made to other crops for which there is demand (e.g., a non-food crop that can be used to produce biofuels). For those now growing niche crops (e.g., crops such as apples and broccoli in cool summer regions such as upstate New York and New England; tomatoes in regions where nighttime temperatures are cool enough for fruit to set; etc.), warming is likely to make such regions uncompetitive for continued production of these crops. Because soils are typically not fertile enough to compete economically with regions now growing warm season crops, farming in such regions is also likely to be threatened. Thus, while overall food production in regions such as the U.S. is projected to increase, there are likely to be hard times for many farmers (and the rural communities associated with them) as adjustments occur. Lost in the transformation is likely to be the effective role present-day farmers play in caring for the land, which is likely to create ecological challenges because returning such regions as the southern Great Plains to their pre-farming vegetation is unlikely to be successful due to the altered climatic conditions.

For natural systems such as forests and grasslands, the situation is more problematic. Each ecosystem type has a set of preferred conditions, as is evident from the changing distributions of types of forest ecosystems going poleward or up a mountain. As climatic conditions shift, the preferred ranges for each type of ecosystem will shift, and numerical models that simulate this process indicate that the projected changes in climate over the 21st century will have profound effects. Starting from the Arctic (and focusing on the coarsest subdivision of ecosystem types), the tundra, which is summer home and nesting ground for many migrating birds and mammals, will be squeezed against the Arctic Ocean as the boreal forest becomes established further and further to the north. Across the United States and Canada, temperate forests and grasslands will push northward, with the northeast mixed forest giving way to more temperate vegetation and with forests giving way to savanna and grasslands in regions where precipitation does not increase enough to supply the needed moisture in the face of rising temperatures. For the southeastern and southwestern U.S., this balance will be particularly important. As described in the U.S. National Assessment, if the summertime conditions become warmer and moister, the southeastern mixed forest can persist, but if precipitation does not increase sufficiently, the soils will dry and the temperatures will increase even more, creating a situation where more frequent fires become likely to accelerate the transition to a sparser savanna woodland situation.[30] In the southwestern United States, increased precipitation, particularly in the winter, may be sufficient to increase biological productivity in desert areas, allowing greater vegetation growth in winter. While seemingly beneficial, if summers become hotter and remain dry, the potential for increased fire is significant (e.g., increased wintertime growth of chaparral would likely only increase the likelihood of periodic fires, which can be particularly threatening to communities in the West).[31]

While adapting to a situation of relatively slowly shifting ecosystems on the continental scale may seem comparable to adapting to the reforestation of the Northeast over the 20th century, the actual situation on the local scale, both for wildlife and for communities, is likely to be much more challenging. This is the case because there are significant variations in the response of the different plant species that make up the ecosystems to the changes in CO_2 and climate, and this will mean that the preferred ranges of different species will shift by different amounts and at different rates, thus pulling apart current ecosystems without there becoming stable climatic conditions in which new ecosystems can evolve—instead, everything will be changing at once.

Determining the thresholds that might lead to abrupt changes in the functioning of natural systems is, however, particularly difficult, and there are likely to be thresholds or tipping points that initiate a sequence of changes beyond which sys-

tems are likely to collapse. For example, a temperature increase of about 1°C per decade since 1970 in the Kenai Peninsula in Alaska has caused permafrost melting and allowed the over-wintering of spruce bark beetles and the influx of additional disease vectors, weakening the trees, and enhancing the extent and intensity of wildfire. Together, these effects have led to the sudden and widespread loss of the white spruce forest, and to a situation in which, even were the new climatic conditions stable, it would take centuries for new species to develop into a new, fully mature ecosystem; with stable conditions not likely for at least many decades, development of a new, mature forest system is likely far off in the future. As another example of the sensitivity of extant ecosystems, a massive die-off of pinyon pine (*Pinus edulis*) covering 12,000 square kilometers in the southwestern United States was observed during the recent severe drought. Although the soil moisture deficit was no worse than the one endured in the 1950s, the higher average temperature appears to have combined with the extreme dryness to make the trees more vulnerable to attacks from bark beetles.[32]

Increased frequency of droughts, wildfires, floods, and other extremes, including greater damage from increased and more persistent winds and precipitation from tropical cyclones,[33] are other types of changes that have the potential to exceed the adaptive capacity of existing ecosystems. In addition, more frequent fires and the reduced productivity of some ecosystems will limit the amount of carbon being taken up and stored by the biosphere, thus leaving a larger fraction of the emitted CO_2 to exacerbate global warming. For example, the recent Indonesian fires driven by ENSO drying and human land use changes led to significant releases of CO_2 to the atmosphere. A recent international comparison of coupled carbon climate simulations[34] found that all of the models projected some destabilization of tropical ecosystems, leading to soil drying, reduced plant/tree growth, and increased occurrence of fire and net emission of CO_2 to the atmosphere, thereby accelerating warming (positive feedback loop).[35] Models typically suggested that by 2100 these "carbon-climate" feedbacks would lead to the atmospheric CO_2 concentration being higher by 20 to 200 ppmv[36] and additional warming of 0.1 to 1.5°C, with the worst-case model scenario projecting the complete die off of the Amazon rain forest. These feedbacks are not yet well understood or represented, requiring coupled treatment of climate change, CO_2 fertilization, nitrogen limitation, and the ability of trees to tap deep soil horizon water; however, these processes do indicate the potential for the likely outcome being more toward the upper end of the IPCC range of possibilities.[37]

Because projected shifts in the frequency, timing, intensity, and location of precipitation will lead to all sorts of challenges, issues relating to freshwater resources, although of a variety of types, were a common thread across all regions in the U.S. National Assessment (see Table 1 for a brief summary of key regional consequences). For example, the increased likelihood of additional wintertime precipitation in the western U.S., as projected in both models used in the U.S. National Assessment, increases the potential for mudslides and high river levels as well as increasing the likelihood of mountain precipitation falling as rain, causing accelerated loss of the snowpack, a further increase in runoff and an even greater likelihood of flooding. At the same time, warmer temperatures will lead to a rise in the snowline and, on average, a reduction in the springtime snowpack that is so vital for sustaining stream and river flows into the summer. For the rest of the U.S., projections indicate a continuation of the shift of precipitation toward more precipitation falling in the more intense (*i.e.,* convective) rainfall events. Reducing the time for rainfall to seep into aquifers has the effect of increasing runoff, especially once the upper layer of soil has become saturated, thereby increasing the likelihood of high river levels and flooding. Warmer summertime temperatures, and a greater interval between significant rainfall events, are projected by many of the models to lead to increased evaporation of soil moisture in the Great Plains, and so a more rapid onset of drought conditions. For the Great Lakes, most models project a few foot lowering of lake levels as the increase in summertime evaporation exceeds the increase in winter precipitation, significantly impacting community, recreational and commercial use of lake waters.[38] Reduced duration and extent of snowfall will also affect the Northeast and other areas, likely shortening the ski season and lengthening the time for warm weather recreational use of the landscape, assuming drying and fire do not become threats.

In the Arctic, the melting back of snow cover, river ice, and permafrost, combined with offshore melting back of sea ice, will have significant effects on wildlife and on movement generally across the region. For many types of wildlife, the snow cover provides protection and even habitat, and climate change is likely to break vital links (e.g., lemmings and voles survive the winter mostly between the snow layer and the underlying tundra, and their loss would deplete food resources for snowy owls and foxes, etc.). Reindeer and caribou depend on the snow cover to protect

vegetation that serves as winter feed, and episodic freeze-thaw conditions can create ice crusts that cannot be easily broken, reducing access to the food necessary to survive. The migrating herds also depend on frozen river ice in springtime to cross rivers along migration routes to summer breeding grounds.[39] Warmer conditions are already leading to new species appearing in the Arctic, and these new species will tend to push existing species northward, likely eventually to extinction as the land ends and the Arctic Ocean begins.

In addition, the melting of permafrost (and frozen sediments on the continental shelves) has the potential to release large amounts of methane (CH_4) that is tied up in hydrates. On a per molecule basis, methane is roughly 20 times as effective as trapping infrared radiation as is a CO_2 molecule, which is why there is so much attention being devoted to human-induced changes in methane concentrations (human contributions have caused about a 150 percent increase in the preindustrial CH_4 concentration). While permafrost melting has begun, determining how much CH_4 is being released has proven quite difficult and so the IPCC projections do not yet account for the potential warming influence of such releases, but the potential for substantial releases is quite significant, especially because warming in the Arctic is projected to be greater than for the world as a whole.

Continued warming and changes in snowfall are also likely to further increase the ongoing retreat of mountain glaciers and the great ice sheets. In virtually all regions of the world, including on high tropical mountains, glaciers are retreating at a rapid rate. Because the annual glacier runoff in many cases serves as water resources for wildlife and communities, the eventual loss of the glaciers is likely to have very significant consequences in many regions around the world. The area of the Greenland Ice Sheet that melts each year is also increasing, and satellite observations indicate that ice mass is decreasing.[40] What appears to be happening is that rather than small puddles forming and then refreezing in the fall, larger puddles are forming, and then finding channels and crevasses to flow to the bedrock and eventually into the ocean, allowing a greater fraction of the increase in downward infrared radiation caused by the higher greenhouse gas concentrations to go into melting of ice as opposed to the very energy intensive process of evaporation of water. The situation is much like what would happen if one of those decorative ice statues on banquet tables were taken out of a freezer for longer and longer intervals—if out for only a short period, the thin meltwater layer on the statue might refreeze when the statue is put back in the freezer; however, if kept out longer, the meltwater created each time would be lost, and soon there would be no ice statue at all.[41]

Projections are that high-latitude warming of a few degrees Celsius (so perhaps 5°F), which is projected for the second half of the 21st century, would be likely to lead to the melting of roughly half of the Greenland Ice Sheet over a period of up to several centuries,[42] mirroring a similar event that occurred during the last interglacial,[43] likely mainly as the result of a particular set of variations in the Earth's orbit at that time that brought comparable warmth to high northern latitudes. The effects on sea level of such extensive changes are discussed in the next section.

While much of the above discussion has focused on the projected changes in seasonal to annual timescale changes, what really has most effect on people and the environment are the extremes of the weather that are combined to get the changes in the averages. The weather (*i.e.,* the instantaneous state of the atmosphere) is determined by the interaction of all of the various forcings and gradients in the global system. Observations indicate that day-to-day weather conditions tend to vary about the mean conditions in a more-or-less standard way, creating a bell-shaped distribution of conditions with a few instances much above and below the average and a greater likelihood of the conditions being near the average expected at each time of year. The projected change in climate will shift this distribution, moving the average higher, and thereby creating a much greater likelihood that conditions will exceed a particular threshold (e.g., 90 or 95°F). The likelihood of presently unusual events could also be changed if the shape of the bell-like distribution is changed, which could occur, for example, if the characteristics of the global circulation are changed (e.g., by moving the winter jet stream relative to mountain ranges such as the Himalayas, or by altering the oceans in ways that affect the irregular cycling or intensity of El Niño or La Niña events).

As a result of the changes in climate, conditions such as heat waves (which exacerbate the heat index and thermal stress in cities[44]) and drought conditions favorable for wildfires are expected to become more frequent and more intense. In fact, Dai et al. (2004) calculate that the amount of land experiencing severe drought has more than doubled in the last 30 years, with almost half of the increase being due to rising temperatures rather than decreases in rainfall or snowfall.[45] Not surprisingly, therefore, observations indicate that wildfires have been increasing on all continents, particularly sharply in North America, and projections are that this trend

is likely to intensify with further increases in surface temperature.[46] In addition, freeze events, which are important to controlling many types of pests and associated diseases, are projected to be less likely. As already mentioned, the occurrence of more intense and more frequent heavy rainfall events is likely to increase the occurrence of flooding. Analyses by Milly et al. (2002) indicate that the frequency of very large floods has increased substantially during the 20th century, which is consistent with climate model simulations, and modeling studies suggest that the trend will continue in the future.[47] With respect to the potential severity of this type of effect, results from the Canadian climate modeling group cited in the U.S. National Assessment indicate that the return period of what are now once in a hundred year events will, by the end of the century, likely be reduced to about once every 30 years, with even more severe events occurring once every hundred years. In that much of society's infrastructure is only designed to withstand once in a hundred year events, having more severe events occurring more often than once a century is likely to increase the likelihood of very damaging events,[48] causing very adverse and costly impacts for both society and the environment.

Some media reports and criticisms by skeptics question the rising concern about the increasing risks from more intense and more frequent occurrence of extreme weather events, indicating that no specific event can be attributed to global warming. To better understand the situation, consider the simple analogy of the Earth's weather being equivalent to a pot of slowly boiling water, with each bubble indicating an extreme event somewhere across the globe. If the heat under the pot is turned up, there will be more bubbles, some of which are the size of the previous largest bubble and perhaps some even larger. There is no way to say that any particular bubble was due to the increased heat or was bigger because of it, yet clearly the intensified bubbling is due to the additional heat. Now, the real world situation is further complicated by seasonal changes (roughly equivalent to the heat being slowly turned up and down, but each time to higher levels), spatial linkages resulting from the oceanic and atmospheric circulations (roughly equivalent to adding noodles to the boiling water), and the presence of mountains and other geographic features (roughly equivalent to having a pot of varying shape and thickness); as a result formally detecting the changes in extreme events is indeed a challenge. But there is no question that adding heat to the system will lead to greater extremes (were the subtropics not so warm, the incidence of tropical cyclones would be much less).

Consequences at the Coastal Interface of the Terrestrial and Marine Environments

At coastlines, the consequences of the changes in marine and terrestrial components come together. Because the coastal region provides habitat to so many species, from shrimp to shore birds, and from plant species to humans, past and projected changes occurring in this boundary environment have particular importance for the environment and society.

Bays, inlets, estuaries, barrier islands, marshes, wetlands, and more provide habitat to a wide range of species, in some cases year-round and in other cases at particular times as species migrate from one region to another. These regions are breeding grounds for fish and fowl, and those, including humans, that live off of them. The particular conditions each species needs results from the balance between the saline ocean waters and the terrestrial freshwaters, all mixed by the tides and ocean currents and moderated and mixed by the particular weather conditions ranging from mild sea breezes to raging storms. Nutrients are provided by the oceanic and river flows and by atmospheric deposition, all then cycled through by the chain of living plants and animals (including both terrestrial and marine life). Productivity has been able to develop as a result of the relative stability of the shoreline environment, with niches being filled to make optimal use of available resources.

Climate change is not the only stress that is now being imposed on this environment. Harvesting, air and water pollution, encroachment, toxics, excessive nitrogen deposition, oxygen deprivation, and more are all creating stresses, and now comes sea level rise and climate change (*i.e.,* warming, changes in precipitation that alter runoff, intensified storms, changes in winds and ocean currents, and more). Sea level has been roughly stable for the past several thousand years, yet has recently begun to rise. Warming of ocean waters (which leads to their expansion, just as mercury expands to fill a thermometer as the temperature increases) and water added to the ocean, likely mostly from melting of mountain glaciers, caused global sea level to rise 4–8 inches (10–20 cm) during the 20th century.[49] For the 21st century, the early projections have been that sea level will go up by another 12–20 inches (30–50 cm);[50] with the apparent acceleration in the melting of the Greenland Ice Sheet that has been observed,[51] the Arctic Climate Impact Assessment con-

cluded that projections of sea level rise for the 21st century could quite possibly exceed 20 inches (50 cm), reaching toward the upper limit of the IPCC projections. What is particularly problematic is that the factors contributing the most to sea level rise, namely thermal expansion and the ultimate melting of the Greenland and West Antarctic Ice Sheets, are likely to continue to contribute to sea level rise for centuries after the rise in greenhouse gases is halted, meaning that significant areas of the shoreline will be inundated and lost over coming decades and centuries, and that protection of the most valuable regions through levee construction needs to receive early attention.[52] To date, no nation has prepared for sea level rise of a meter or more within a century, but the possibility warrants appropriate planning beyond normal disaster preparedness.

While the rise in sea level itself might seem small, when amplified by the effects of storms creating waves and storm surges, the situation is particularly threatening. In the Arctic, the melting away from the shore of the sea ice away has allowed winter waves to pound the barrier islands, causing significant erosion. This is particularly a problem because coastal regions are where many native communities have been located, often for thousands of years, in order to harvest the bounty of both the land and the ocean. The most endangered community is currently Shishmaref, which is being eroded away so rapidly that community relocation has already started. As the Government Accountability Office has projected,[53] relocation of all the endangered villages is going to be very costly. Both the climate changes themselves and the relocations will lead to substantial disruption of subsistence harvesting[54] and indigenous culture and traditions that have sustained these communities through thousands of years.

For coastal regions exposed to hurricanes and the waves and the storm surges that they create, the danger is also very great. While international assessments have generally suggested that developing countries are more vulnerable to global warming than developed nations because they lack the resources to be able to adapt, the developed nations have at risk far greater investments in coastal infrastructure, including roads, highways, railroads, airports, ports, sewage treatment facilities, and residential and commercial buildings. Many of these structures are fully exposed to the oceans, unlike New Orleans, which at least at one time was protected by extensive wetlands. With the power and duration of intense hurricanes observed to be increasing, and with greater changes likely ahead as ocean temperatures continue to rise, the coastal region is particularly at risk. While building levees is likely to be able to work for a while, if sea level rise reaches a few meters within a few centuries, retreat is ultimately going to be required in many regions. Disrupted coastlines are also likely to disrupt the resident and migrating wildlife. While some new wetlands may be formed further inland, it is unlikely that such new areas will be as extensive or as able to fill the many roles of existing areas, especially as the process of coastal inundation will be continuous rather than allowing full development at some altered, but fixed, change in sea level.

Summary and Concluding Thoughts

While the discussion above has focused on the great variety of changes and interactions that the increase in the CO_2 concentration and changes in climate are leading to (and the above list is only a sampling), what will be experienced by the environment and society will be all of these changes together, plus the impacts of all of the other changes going on, ranging from air and water pollution to resource utilization and land cover change. While a number of these can be (and are being) ameliorated by regulations and policy, climate change presents several unique aspects. First, climate change will keep growing and growing—it is an influence that can only be slowed, not reversed (at least in any reasonable time horizon). Second, it is fully global, and because the world is environmentally and economically interconnected, impacts in one location can create impacts in other locations. And third, the changes are larger and occurring more rapidly than can be accounted for using any analogs to the past, making very real the potential for surprises, unexpected changes, unidentified thresholds, and tipping points. As Australian author and scientist Barrie Pittock has put it, "Uncertainty is inevitable, but risk is certain."[55]

For the natural world, change is already evident. Analyses by Parmesan and Yohe (2003) indicate with very high confidence that a large fraction of the plant and animal species studied are showing a response consistent with that expected to result from changes in climate.[56] The types of responses include shifts in range (e.g., the Inuits are spotting types of birds never seen before that far north), changes in number and vitality (e.g., the polar bear population around Hudson's Bay), and unprecedented susceptibilities (e.g., to pest outbreaks). There is no question that the natural world is changing, and the main question is how much change can occur before changes in keystone species begin to cause the collapse of ecosystems (e.g., of the

Amazon rainforest[57]) and significant reductions in the ecosystem services (e.g., air and water purification, food and fiber generation, fish and shrimp production) that these systems provide to society. Of particular concern are how all of these changes affect migrating species from birds to butterflies and fish to whales, for they have generally developed a dependence on a timeline of resources at particular locations in order to survive, and significant loss could occur from substantial disruption of any of them.

While modern society may seem less dependent on the natural world, many linkages remain, not only between communities and nearby ecosystems, but also with conditions around the world. Increased temperatures (along with higher absolute humidity—so much higher heat indices) will stress those not able to stay in and pay for air-conditioned space. While those in colder climates that have tight houses can readily transfer savings on heating bills to pay for increased cooling, those in more open homes in presently southern climates will have to invest in considerable structural upgrading to make air-conditioning a viable remedy. That the cost of upgrading will be high, and the need for it greatest among the poor, will create a serious issue of equity, with the least fortunate responsible for the lowest energy use yet suffering the largest consequences.

The effects will not only be personal. Not only do modern societies draw resources and food from ecosystems and countries around the world, but products also come from around the world and investment portfolios typically include a mix of international stocks, coupling one's economic state to the state of the world. In addition, with people traveling extensively for business and pleasure, the health of people around the world is interconnected, and what happens in one location can soon affect those in other locations. In that warm conditions are generally more favorable for the presence of disease vectors such as mosquitoes, warming will lead to the loss of the ally of freezing conditions for helping to control mosquito populations. As a result, except in regions (such as the U.S.) where rigorous public health practices and community building standards have over time separated the disease from the disease vector and from people, warming and increased precipitation are likely to exacerbate the likelihood of exposure to disease vectors.[58] Even in countries such as the U.S., isolated occurrences are likely given the magnitude of international travel, and so extra resources will have to be devoted to maintaining high standards and quickly addressing new infestations (e.g., by spraying for mosquitoes). Changes in the distribution and level of activity of various plant species can also exacerbate health problems, as for example the increased production of pollen that can exacerbate incidence of asthma.[59]

The shifting climatic patterns and rising sea level are likely to be most problematic for small countries and other similarly sized entities. For island nations made up mainly of coral atolls, rising sea level and higher storm surges are already having deleterious effects on aquifers, and continuing sea level rise is likely to inundate several island nations over the coming century. For small countries, especially those that have focused on growing a particular crop, shifting climatic patterns are likely to require changes in crop species, which is likely to be difficult to compete as there will likely be the need to break into new markets. Whereas many indigenous peoples, including the American Indian, have long traditions of adaptation, at the root of previous successes was often the ability to relocate; with tribal reservations now fixed, community relocation is no longer possible, and medicinal plants and other historic species are likely to shift to quite removed locations, negating the passed on ecological wisdom developed over so many generations.

For many regions, changes in water resources will be the most important effect, with increased competition for reduced resources among agricultural, community, industrial and ecological interests. For coastal regions, sea level rise and increases in storm intensity will pose the most important threats, requiring both enhancement of resilience in the near-term and possible relocation in the long-term. For those in urban areas, the increased likelihood of heat stress conditions and higher air pollution levels[60] may well pose the most significant threat. Because the particular situation of each region will depend on its individual circumstances, as indicated in Table 1, it is vital that the Nation have an ongoing assessment activity that helps regions and sectors to understand, prepare for, and ameliorate the most deleterious circumstances. Such an effort, as is called for in the Global Change Research Act of 1990 [Pub.L. 101–606], was begun in earnest in 1997 with the undertaking of the U.S. National Assessment; that this effort was essentially terminated in 2001 after having made significant progress in involving stakeholders in regional activities has been most unfortunate.

What is most clear is that global climate change is underway and that the risk of adverse consequences for both marine and terrestrial environments is quite high. While it will take substantial efforts and many decades to limit emissions of green-

house gases and bring climate change to a stop as called for in the U.N. Framework Convention on Climate Change ratified by the U.S. Senate in 1992, that virtually no effort is being made by the U.S. to accomplish this in the face of all the scientific information about impacts is most unfortunate. For the people of the Arctic and of the U.S. whom I have had the privilege of representing in assessment activities, I urge your most urgent consideration of a national effort to prepare for the inevitable climate change that lies ahead and to take actions to sharply limit the climate change that will be brought on by future emissions.

Websites of Particular Relevance to Understanding of Climate Impacts

U.S. National Assessment of the Potential Consequences of Climate Variability and Change (*http://www.usgcrp.gov/usgcrp/nacc/default.htm*)

Arctic Climate Impact Assessment (*http://www.acia.uaf.edu/*)

Intergovernmental Panel on Climate Change: (*http://www.ipcc.ch/*)

Millennium Ecosystem Assessment: (*http://www.millenniumassessment.org/en/index.aspx*)

Climate Institute (*http://www.climate.org/CI/index.shtml*)

Table 1: Examples of important climate change consequences affecting regions of the U.S.*

Regions and Subregions	Examples of Key Consequences Affecting:		
	the Environment	the Economy	People's Lives
Northeast—New England and upstate NY, Metropolitan NY, Mid-Atlantic	Northward shifts in the ranges of plant and animal species (e.g., of colorful maples); Coastal wetlands inundated by sea-level rise.	Reduced opportunities for winter recreation such as skiing; increased opportunities for warm-season recreation such as hiking and camping; Coastal infrastructure will need to be buttressed.	Rising summertime heat index will make cities less comfortable and require more use of air-conditioning; Reduced snow cover.
Southeast—Central and Southern Appalachians, Gulf Coast, Southeast	Increased loss of barrier islands and wetlands, affecting coastal ecosystems; Changing forest character, with possibly greater fire and pest threat.	Increased productivity of hardwood forests, with northward shift of timber harvesting; Increased intensity of coastal storms threaten coastal communities.	Increased flooding along coastlines, with increased threat from storms; Longer period of high heat index, forcing more indoor living.
Midwest—Eastern Midwest, Great Lakes	Higher lake and river temperatures cause trend in fish populations away from trout toward bass and catfish.	Increasing agricultural productivity in many regions, ensuring overall food supplies but possibly lowering commodity prices.	Lowered lake and river levels, impacting recreation opportunities; Higher summertime heat index reduces urban quality of life.
Great Plains—Northern, Central, Southern, Southwest/Rio Grande Basin	Rising wintertime temperatures allow increasing presence of invasive plant species, affecting wetlands and other natural areas; Disruption of migration routes and resources.	Increasing agricultural productivity in north, more stressed in the south; Summertime water shortages become more frequent.	Altered and intensified patterns of climatic extremes, especially in summer; Intensified springtime flood and summertime drought cycles.

Table 1: Examples of important climate change consequences affecting regions of the U.S.*—Continued

Regions and Subregions	Examples of Key Consequences Affecting:		
	the Environment	the Economy	People's Lives
West—California, Rocky Mountains/Great Basin, Southwest/Colorado River Basin	Changes in natural ecosystems as a result of higher temperatures and possibly intensified winter rains.	Rising wintertime snowline leads to earlier runoff, stressing some reservoir systems; Increased crop yields, but with need for greater controls of weeds and pests.	Shifts toward more warm season recreation activities (e.g., hiking instead of skiing); Greater fire potential created by more winter rains and dry summers; Enhanced coastal erosion.
Pacific Northwest	Added stress to salmon populations due to warmer waters and changing runoff patterns.	Earlier winter runoff will limit water availability during warm season; Rising forest productivity.	Reduced wintertime snow pack will reduce opportunities for skiing, increase opportunities for hiking; Enhanced coastal erosion.
Alaska	Forest disruption due to warming and increased pest outbreaks; Reduced sea ice and general warming disrupts polar bears, marine mammals, and other wildlife.	Damage to infrastructure due to permafrost melting; Disruption of plant and animal resources supporting subsistence livelihoods.	Retreating sea ice and earlier snowmelt alter traditional life patterns; Opportunities for warm season activities increase.
Coastal and Islands—Pacific Islands, South Atlantic Coast and Caribbean	Increased stress on natural biodiversity as pressures from invasive species increase; Deterioration of coral reefs.	Increased pressure on water resources needed for industry, tourism and communities due to climatic fluctuations, storms, and saltwater intrusion into aquifers.	Intensification of flood and landslide-inducing precipitation during tropical storms; More extreme year-to-year fluctuations in the climate.
Native People and Homelands	Shifts in ecosystems will disrupt access to medicinal plants and cultural resources.	The shifting climate will affect tourism, water rights, and income from use of natural resources.	Disruption of the religious and cultural interconnections of Native people and the environment.

*MacCracken, M. C., 2001: Climate Change and the U.S. National Assessment, pp. 40–43 in *McGraw Hill Yearbook of Science and Technology 2002,* McGraw-Hill, New York, 457 pp.

Attachment 1: Arctic Temperature Change—Over the Past 100 Years

Released June 28, 2005 by Gordon McBean, Lead author of Chapter 2, ACIA Report. The authors of Chapter 2 are: G. A. McBean, G. Alekseev, D. Chen, E. Forland, J. Fyfe, P.Y. Groisman, R. King, H. Melling, R. Vose and P. H. Whitfield.

This note has been prepared in response to questions and comments that have arisen since the publication of the Arctic Climate Impact Assessment overview document—*"Impacts of a Warming Arctic."* It is intended to provide clarity regarding some aspects relative to the material from Chapter 2 *Arctic Climate—Past and Present* that will appear in full with the publication of the ACIA scientific report in 2005.

The authors of Chapter 2 began their work in 2000. It was recognized that the observational data base for the Arctic is limited, with few long-term stations and a paucity of observations in general. Because at that time the published literature on Arctic temperature changes was not comprehensive nor up-to-date, it was decided to undertake a new set of calculations, based only on data sets that were fully documented in the literature, but updated to the present, using the documented procedures. The Global Historical Climatology Network (GHCN) data base (updated from Peterson and Vose, 1997) was selected for this analysis. A comparison was made with the Climatic Research Unit (CRU) data base (Jones and Moberg, 2003) because both data bases were used in the Third Assessment Report (IPCC, 2001b) to summarize the patterns of temperature change over global land areas since the late 19th century. The GHCN dataset includes selected quality controlled long-term stations suitable for climate change studies. The U.S. National Climate Data Center was asked to do the calculations since they had both datasets in their archives.

There are several possible definitions of the Arctic depending on, for example, tree line, permanent permafrost, and other factors. It was decided for purposes of this analysis that the latitude 60°N would be defined as the southern boundary. Although somewhat arbitrary, this is no more arbitrary than choosing 62°N, 67°N or any other latitude. Since the marine data in the Arctic are very limited in geographical and temporal coverage, it was decided, for consistency, to only use data from land stations.

The analysis showed that the annual land-surface air temperature variations in the Arctic (north of 60°N) from 1900 to 2002 using the GHCN and the CRU datasets led to virtually identical time series, and both documented a statistically significant warming trend of 0.09 °C/decade during that period (Figure 1). Annual land-surface air temperature trends were calculated for the periods 1900–2003, 1900–1945, 1946–1965, and 1966–2003. Trends were calculated from annually averaged gridded anomalies using the method of Peterson et al. (1999) with the requirement that annual anomalies include a minimum of 10 22 months of data. For the period 1900–2003, trends were calculated only for those 5° x 5° grid boxes containing annual anomalies in at least 70 of the 104 years. The minimum number of years required for the shorter time periods (1900–1945, 1946–1965, and 1966–2003) was 31, 14, and 26, respectively.

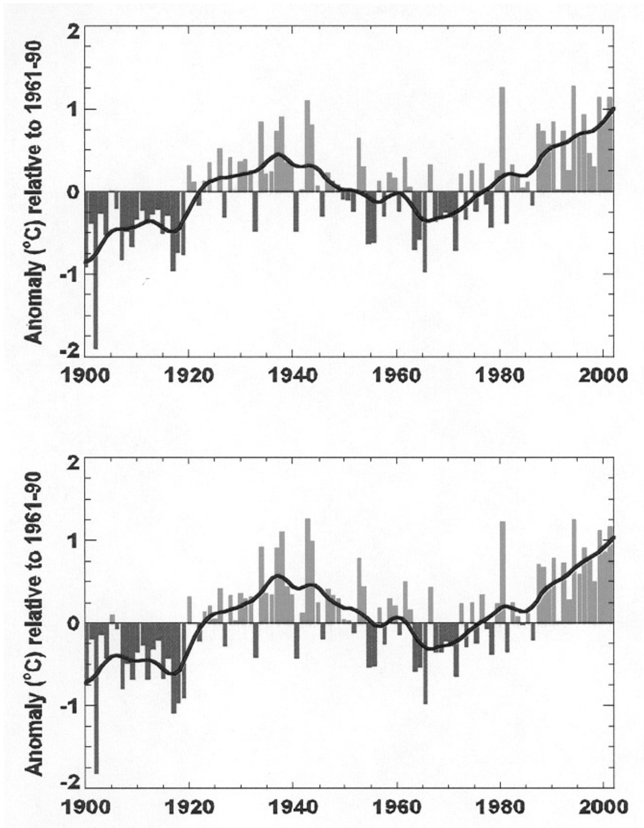

Figure 1. Annual anomalies of landsurface air temperature (°C) from 60–90°N for the period 1900–2002. Anomalies are relative to a 1961–90 base period. The smoothed curve was created using a 21-point binomial filter giving near decadal averages. Panel (a)(upper) depicts the GHCN time series (updated from Peterson and Vose, 1997), and panel (b)(lower) depicts the CRU time series (Jones and Moberg, 2003).

In response to critical comments about the ACIA analysis of the temperature record, it is important to note that the choice to use the CHCN dataset was made before the analysis was done, before the Polyakov et al. (2002) paper was published and based on the logical arguments that it was the most comprehensive land-station data base available and was well documented in the literature. As noted, the other well-documented data base, of the CRU, gave virtually identical results.

It needs to be stressed that the spatial coverage of the region north of 60° N is quite varied. During the period (1900–1945), there are 7 grid boxes meeting the requirement of 31 years of data in the Alaska/Canadian Arctic/West Greenland sector. The largest number of grid boxes is in the North Atlantic sector (East Greenland/Iceland/Scandinavia) with 13 grid boxes. There were 10 grid boxes over Russia. The coverage for periods since 1945 is more uniform. Based on these analyses, the annual land-surface air 23 temperature (°C) from 60–90°N, smoothed with a 21-point binomial filter giving near decadal averages, were warmer in the most recent decade (1990s) than they were in the 1930–1940s period.

The analysis of Polyakov et al. (2002) showed the 1930–1940s period warmer than the most recent decade. They used individual stations and the distributions of stations, according to the Figure 1 in their paper, was quite varied for different time periods. The total number of stations of more than 65 years is 8 stations in the Alaska/Canada/West Greenland sector compared to 43 stations in the North Atlantic/Russian sector. Over the whole period of record, their analysis considered 18 sta-

tions for the Alaska/Canada/West Greenland sector compared with 50 stations from the North Atlantic/Russian sector. The Polyakov paper also considered only maritime (or coastal) stations north of 62°N, while the analysis presented in Chapter 2 of the ACIA report considered all land stations north of 60°N. It should be noted that several of the locations of greatest warming in recent decades are apparent as a result of the continental stations between 60° and 62°N (in Russia, Canada and Alaska).

Another important paper is that of Johannessen et al. (2004) who found, with a dataset extensively augmented by Russian station data not previously available, that the "early warming trend in the Arctic was nearly as large as the warming trend for the last 20 years" but "spatial comparison of these periods reveals key differences in their patterns". Their analysis, consistent with the analysis presented in the ACIA Chapter 2, showed that average annual temperatures were higher in the most recent decade than in the 1930–1940 period. Further, the pattern of temperature increases over the past few decades, they note, is different and more extensive than the pattern of temperature increases during the 1930s and 1940s, when there was weak (compared to the present) lower-latitude warming.

Chapter 3 of the ACIA report, entitled "The Changing Arctic: Indigenous Perspectives" documents the traditional knowledge of Arctic residents and indicates that substantial changes have already occurred in the Arctic and supports the evidence that the most recent decade is different from those of earlier in the 20th century.

Although all data bases suffer from a lack of data in the Alaska/Canada/West Greenland sector except for the last 50 years, Polyakov et al. (2002), ACIA Chapter 2, Johannessen et al. (2004), Serreze, et al. (2000) and other analyses all show that the recent decades are warm relative to at least most of the period of instrumental record.

The rate of warming in the recent decades is also much greater than the average over the past 100 years (Figure 2). Least-squares linear trends in annual anomalies of arctic (60° to 90° N) land-surface air temperature from the GHCN (updated from Peterson and Vose, 1997) and CRU (Jones and Moberg, 2003) datasets for the period 1966–2002 both gave warming rates of 0.38 (°C/decade). This is consistent with the analysis of Polyakov et al. (2002) and confirmed with satellite observations over the whole Arctic, for the past 2 decades (Comiso, 2003).

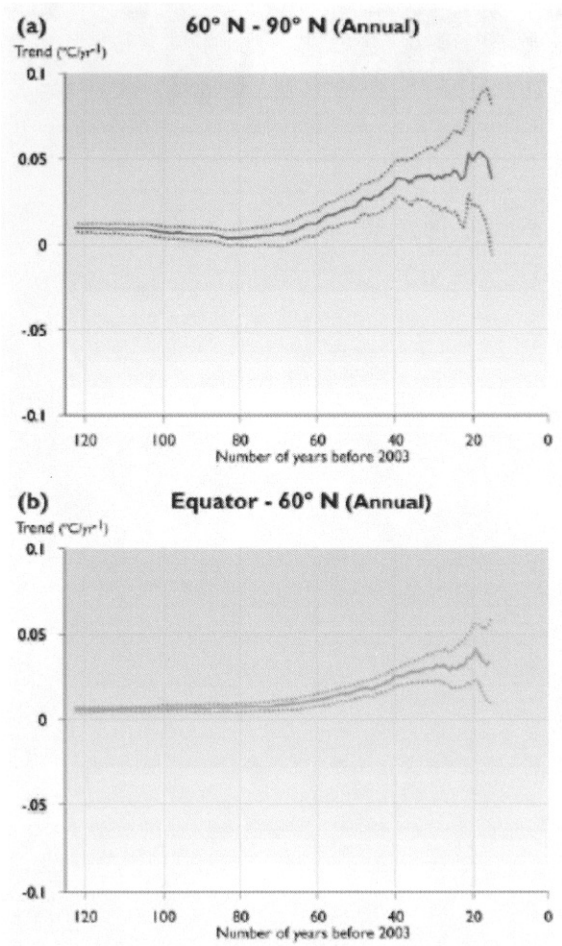

Figure 2. Trends in land-surface air temperatures (solid lines) and their 95 percent significance levels (dashed lines) over the past 120 years for (a) 60° to 90° N and (b) 0 to 60° N (data from the GHCN dataset, updated from Peterson and Vose, 1997).

The modeling studies Johannessen et al. (2004) showed the importance of anthropogenic forcing over the past half century for modeling the arctic climate. "It is suggested strongly that whereas the earlier warming was natural internal climate-system variability, the recent SAT (surface air temperature) changes are a response to anthropogenic forcing". A new paper, published after completion of the ACIA Chapter, by Bengtsson et al. (2004) states in its summary, with reference to the warming of the 1930–1940s: "This study suggests that natural variability is a likely cause . . ."

As stated by the IPCC (2001b), model experiments show "a maximum warming in the high latitudes of the Northern Hemisphere". In reference to warming at the global scale, the IPCC (2001a) also concluded, "There is new and stronger evidence that most of the warming observed over the past 50 years is attributable to human activities". Karoly et al. (2003) concluded that temperature variations in North America during the second half of the 20th century were probably not due to natural variability alone. Zwiers and Zhang (2003) were able to detect the combined effect of changes in greenhouse gases and sulfate aerosols over both Eurasia and North America for this period, as did Stott et al. (2003) for 25 northern Asia (50–

70° N) and northern North America (50–85° N). In any regional attribution study for the Arctic (which has not yet been published), the importance of variability must be recognized. In climate model simulations, the arctic signal resulting from human-induced warming is large but the variability (noise) is also large. Hence, the signal to noise ratio may be lower in the Arctic than at lower latitudes. In the Arctic, data scarcity is another important issue. However, it is implausible to conclude that the warming of the recent decades is not of anthropogenic origins.

In the context of this report, the authors agreed on the following terminology. A conclusion termed as "very probable" is to be interpreted that the authors were 90–99 percent confident in the conclusion. The term "probable" conveys a 66–90 percent confidence.

The conclusions of Chapter 2 were that:

> "Based on the analysis of the climate of the 20th century, it is very probable that the Arctic has warmed over the past century, although the warming has not been uniform. Land stations north of 60° N indicate that the average surface temperature increased by approximately 0.09 °C/decade during the past century, which is greater than the 0.06 °C/decade increase averaged over the Northern Hemisphere. It is not possible to be certain of the variation in mean land-station temperature over the first half of the 20th century because of a scarcity of observations across the Arctic before about 1950. However, it is probable that the past decade was warmer than any other in the period of the instrumental record."

Polar amplification refers to the relative rates of warming in the Arctic versus other latitude bands. Using comparable data sets (the GHCN dataset), the warming for land stations over the region north of 60°N, is almost double that for stations in the latitude bands 0–60°N (Figure 2). The conclusions of Chapter 2 were that:

> "Evidence of polar amplification depends on the timescale of examination. Over the past 100 years, it is possible that there has been polar amplification, however, over the past 50 years it is probable that polar amplification has occurred."

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ENDNOTES

[1] Prepared in cooperation with Dr. Michael MacCracken, chief scientist for climate change programs at the Climate Institute, Washington DC, and Dr. Rosina Bierbaum, Dean of the School of Natural Resources and Environment at the University of Michigan in Ann Arbor.

[2] National Assessment Synthesis Team, 2000: *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change: Overview Report,* U. S. Global Change Research Program, Cambridge University Press, Cambridge UK, 154 pp.

[Also see *Foundation Report,* U.S. Global Change Research Program, Cambridge University Press, Cambridge UK, 612 pp. published in 2001]. The most significant results of the National Assessment were summarized in the *U.S. Climate Action Report—2002,* which was submitted to the U.N. under the Framework Convention on Climate Change as the Third National Communication of the United States of America (thus representing the official position of the U.S. Government in a document formally approved by all of the involved agencies and departments); this document is available from the U.S. Government Printing Office website at *http://bookstore.gpo.gov* and is posted at *http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsUSClimateActionReport.html.*

[3] Arctic Climate Impact Assessment (ACIA), 2004: *Impacts of a Warming Arctic: Arctic Climate Impact Assessment,* Cambridge University Press, 140 pp. [Also see ACIA, 2005, Cambridge University Press, 1042 pp.]

[4] The *Arctic Council* was established on September 19th, 1996 in Ottawa, Canada. The Arctic Council is a high-level intergovernmental forum that provides a mechanism to address the common concerns and challenges faced by the Arctic governments and the people of the Arctic as a means of improving the economic, social and cultural well being of the north. The national members of the Council are Canada, Denmark, Finland, Iceland, Norway, the Russian Federation, Sweden, and the United States of America; the Association of Indigenous Minorities of the North, Siberia and the Far East of the Russian Federation, the Inuit Circumpolar Conference, the Saami Council, the Aleutian International Association, Arctic Athabaskan Council and Gwich'in Council International are Permanent Participants in the Council. Many additional entities participate through a provision that provides for non-arctic states, inter-governmental and inter-parliamentary organizations and nongovernmental organizations to become involved as Official Observers.

[5] The *International Arctic Sciences Committee* (IASC) was founded 28 August 1990 by national science organizations representing all of the arctic countries. It provides the major venue for national science organizations, mostly academies of science, to facilitate and foster cooperation in all fields of arctic research. IASC currently has participation by scientists from Canada, China, Denmark, Finland, France, Germany, Iceland, Italy, Japan, The Netherlands, Norway, Poland, Republic of Korea, Russia, Sweden, Switzerland, United Kingdom, and the United States.

[6] The IPCC's assessments are all published by Cambridge University Press, and are also available over the Internet at *http://www.ipcc.ch.* IPCC's Fourth Impact Assessment Report is due to be completed in 2007.

[7] IPCC, 2001: *Climate Change 2001: The Scientific Basis,* edited by J. T. Houghton et al., Cambridge University Press, 881 pp., see also *http://www.ipcc.ch*.

[8] For example, see *http://data.giss.nasa.gov/gistemp/2005/*. Results of other centers give similar results.

[9] Such reconstructions estimate past values of surface temperature using tree-rings, coral growth patterns, changes in vegetation indicated by changes in pollen preserved in lake sediments, etc.

[10] For example, see Mann, M. E., and P. D. Jones, 2003: Global surface temperatures over the past two millennia. *Geophysical Research Letters* 30, 1820–1824, doi. 10.1029/2003 GL017814. Controversies over the findings reported in this initial paper have largely been addressed over the years since it was published.

[11] See Attachment 1 for an overview by the authors of ACIA's chapter on past climate change regarding the unprecedented patterns of modern warming and recon-

ciling this finding with the analyses of supposed similarly warm conditions in the early to mid-20th century.

[12] The near final draft of a tightly focused assessment by the U.S. Climate Change Science Program (see *http://www.climatescience.gov/Library/sap/sap1-1/third-draft/default.htm*) of trends in surface and upper troposphere temperatures indicates that previous criticisms that warming rates have been significantly different are not valid. This focused assessment reports near resolution of this issue as a result of studies that have identified corrections needed in satellite and balloon records as a result of instrument and observational factors.

[13] These estimates allow for uncertainties in projections of future energy-related emissions. However, two other factors can also introduce uncertainties. First, present models have only a limited treatment of the processes that govern how rapidly CO_2 will be taken up by the land and ocean carbon reservoirs; preliminary studies by Cox et al. (Cox, P.M., R.A. Betts, C.D. Jones, S.A. Spall, and I.J. Totterdell, 2000: Acceleration of global warming due to carbon cycle feedbacks in a coupled climate model, *Nature,* 408, 184–187) and Fung et al. (Fung, I., S.C. Doney, K. Lindsay, and J. John, 2005: Evolution of carbon sinks in a changing climate, *Proceedings of the National Academy of Sciences* (USA), 102, 11201–11206, doi:10.1073/pnas.0504949102) indicate that current models are overestimating the amount of carbon that can be taken up, thus leading to small underestimates of the rate of warming. Second, limits in our estimates of how the climate will respond to changing atmospheric composition are estimated to have the potential to increase or decrease the temperature changes in 2050 by about 0.3°C (roughly 0.5°F) and in 2100 by about twice this amount, with the likelihood (as a result of recent studies of the likely effects of sulfate aerosols) that the change could be greater than estimated more likely than that these are overestimates.

[14] ppmv stands for parts per million by volume, or number of CO_2 molecules per million molecules of air.

[15] See Doney, S.C., 2006: The dangers of ocean acidification, *Scientific American,* 294(3), March 2006, 58–65; and *Ocean Acidification Due to Increasing Atmospheric Carbon Dioxide,* Royal Society, 2005. Available at *http://www.royalsoc.ac.uk/displaypagedoc.asp?id=13314.*

[16] See Kleypas, J. A., R. W. Buddemeier, D. Archer, J-P. Gattuso, C. Langdon, and B. N. Opdyke, 1999: Geochemical consequences of increased atmospheric carbon dioxide on coral reefs, *Science,* 284, 118–120; and Buddemeier, R. W., J. A. Kleypas, and R. B. Aronson, 2004: Coral reefs & global climate change: Potential contributions of climate change to stresses on coral reef ecosystems, Prepared for the Pew Center on Global Climate Change, *http://www.pewclimate.org/global-warming-in-depth/all_reports/coral_reefs/index.cfm.*

[17] See: Orr, J.C., V.J. Fabry, O. Aumont, L. Bopp, S.C. Doney, R.A. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joos, R.M. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet, R.G. Najjar, G.-K. Plattner, K.B. Rodgers, C.L. Sabine, J.L. Sarmiento, R. Schlitzer, R.D. Slater, I.J. Totterdell, M.-F. Weirig, Y. Yamanaka, and A. Yool, 2005: Anthropogenic ocean acidification over the twenty-first century and its impact on marine calcifying organisms, *Nature,* 437, 681–686, doi:10.1038/nature04095.

[18] Levitus, S., J. I. Antonov, and T. P. Boyer, 2005: Warming of the world ocean, 1955–2003, *Geophysical Research Letters,* 32 (L02604), doi: 10.1029/2004GL021592. Levitus et al. find that over 90 percent of the energy trapped by the increasing concentrations of greenhouse gases ends up in the ocean.

[19] Barnett, T. P., D. W. Pierce, K. M. AchutaRao, P. J. Gleckler, B. D. Santer, J. M. Gregory, and W. M. Washington, 2005: Penetration of human-induced warming into the world's oceans, *Science,* 309, 284–287.

[20] For example, see Webster, P. J., G. J. Holland, J. A. Curry, and H.-R. Change, 2005: Changes in tropical cyclone number, duration, and intensity in a warming environment, *Science,* 309, 1844–1846 and Emanuel, K. A., 2005: Increasing destructiveness of hurricane intensity on climate, *Nature,* 326, 483–485.

[21] Anthes, R. A., R. W. Corell, G. Holland, J. W. Hurrell, M. C. MacCracken, and K. E. Trenberth, 2006: Hurricanes and Global Warming—Potential Linkages and Consequences, *Bulletin of the American Meteorological Society,* 87 (May, in press). With regard to the most important limitation in detection studies, it has been the presumption by a number of investigators (e.g., Pielke et al., 2005, *Bulletin of the American Meteorological Society,* 86, 1571–1575) that the response should be a linear trend in hurricane number (or in other factors) over the course of the century that is made dubious by many detection-attribution studies that indicate that human influences led to a time history of Northern Hemisphere temperature change during the 20th century consisting of warming early in the century, a slight cooling

in mid-century (especially in the North Atlantic sector that is key in affecting hurricane characteristics), and then a sharp warming since the 1970s.

[22] Building societal resilience through adaptive efforts could include, in the short-term, more effective evacuation, stronger levees, beach restoration, enhancing vegetation cover of dunes, strengthening of buildings, etc., and longer-term, withdrawal from the most vulnerable areas, enhanced building codes, storm surge barriers (e.g., being proposed to protect New York harbor), adding capacity to evacuation routes, etc.

[23] See for example: Sarmiento, J., R. Slater, R .Barber, L. Bopp, S.C. Doney, A.C. Hirst, J. Kleypas, R. Matear, U. Mikolajewicz, P. Monfray, V. Soldatov, S. Spall, R. Slater, and R. Stouffer, 2004: Response of ocean ecosystems to climate warming, *Global Biogeochemical Cycles,* 18, GB3003, doi:10.1029/2003GB002134.

[24] For example, see report in the *Washington Post,* April 15, 2006 entitled "Warming Arctic is Taking a Toll," which reports on results of a scientific study appearing in the journal *Aquatic Mammals* that walrus calves are being found abandoned at sea (and almost certain to starve and drown) because there is no longer any sea ice for them to rest on in the areas shallow enough for their mothers to feed off the bottom.

[25] Policy Document is available at: *www.acia.uaf.edu/PDFs/ACIA_Policy_Document.pdf*

[26] Karnosky, D. F., K. S. Pregitzer, D. R. Zak, M. E. Kubiske, G. R. Hendrey, D. Weinstein, M. Nosal, and K. E. Percy, 2005: Scaling ozone responses of forest trees to the ecosystem level in a changing climate, *Plant, Cell, and Environment,* 28, 965–981.

[27] Reich, P. B., S. E. Hobbie, T. Lee, D. S. Ellsworth, J. B. West, D. Tilman, J. M. H. Knops, S. Naeem, and J. Trost, 2006: Nitrogen limitation constrains sustainability of ecosystem response to CO_2, Nature, 440, 922–925.

[28] Indeed, a number of studies suggest that, along with technology and seed enhancements, the increased CO_2 concentration is already contributing to higher yields.

[29] Note, however, that greater year-to-year variability or more frequently exceeding various temperature and/or moisture (or dryness) thresholds may make optimization to a narrow range of climatic variables more risky, and farmers may instead choose not to select seed strains that tolerate a wider range of conditions in exchange for slightly reduced productivity. A key determinant will be how rapidly improvements are made in the skill of seasonal forecasts, a topic on which research attention is being closely focused.

[30] National Assessment Synthesis Team, 2001: *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change: Foundation,* U.S. Global Change Research Program, Cambridge University Press, 612 pp. Available at *http://www.usgcrp.gov/usgcrp/nacc/default.htm*.

[31] Ibid.

[32] Breshears, D. D., et al. 2005: Regional vegetation die-off in response to global-change-type drought, *Proceedings of the National Academy of Sciences,* 102 (Oct. 18), 15144–15148. Available at *http://www.pnas.org/cgi/doi/10.1073/pnas.0505734102.*

[33] Emanuel, K., 2005: Increasing destructiveness of tropical cyclones over the past 30 years, *Nature* 436, 686–688.

[34] Friedlingstein, P., P. Cox, R. Betts, W. von Bloh, V. Brovkin, S. Doney, M. Eby, I. Fung, B. Govindasamy, J. John, C. Jones, F. Joos, M. Kawamiya, W. Knorr, K. Lindsay, H.D. Matthews, T. Raddatz, P. Rayner, C. Reick, E. Roeckner, K.-G. Schnitzler, R. Schnur, K. Strassmann, S. Thompson, A.J. Weaver, and N. Zeng, 2006: Climate-carbon cycle feedback analysis; Results from the C4MIP model intercomparison, *Journal of Climate,* in press.

[35] See, for example, the Cox et al. and Fung et al. references provided above.

[36] For comparison, the CO_2 increase from preindustrial to the present has been about 100 ppmv.

[37] Beedlow, P.A., D.T. Tingey, D.L. Phillips, W.E. Hotsett, and D.M. Olszyk, 2004: Rising atmospheric CO_2 and carbon sequestration in forests, *Ecological Environment,* 2, 315–322.

[38] Warmer lake temperatures also mean delayed formation of lake ice in the winter, perversely allowing a longer period for lake effects storms to dump snow on the surrounding regions.

[39] Arctic peoples and the energy industry also depend on the frozen ground to enable moving around the Arctic; warming has already reduced by about half the number of days the ground is hard enough for movement of some oil-drilling equipment.

[40] See "Changes in the Velocity Structure of the Greenland Ice Sheet" by Eric Rignot and Pannir Kanagaratnam, *Science* Vol 311 17 February 2006, as well as "The Greenland Ice Sheet and Global Sea-Level Rise by Julian A. Dowdeswell, *Science* Vol 311 17 February 2006, and also see Paterson, W.S.B., and N. Reeh, 2001: Thinning of the ice sheet in northwest Greenland over the past forty years, Nature, 414, 60–62.

[41] Note that throughout this process, the temperature of the ice surface when out on the banquet table would still be at the freezing point, even with an infrared lamp shining on it. What matters is the amount of heat being delivered while the temperature is fixed at the melting point—not that the temperature has not risen (as some Skeptics use as an argument to try to find fault with attributing the unprecedented melting back of glaciers to the unprecedented human-induced increase in greenhouse gas concentrations.

[42] See Gregory, J.M., P. Huybrechts, and S.C.B. Raper, 2004: Climatology: Threatened loss of the Greenland Ice Sheet, *Nature,* 428, 616; doi:10.1038/428616a. The IPCC's Third Assessment Report suggests that the time scale for such melting would be millennia, but the recent identification of the meltwater runoff mechanism for more rapid melting is likely to lead to reductions in the estimates included in future assessments.

[43] That such melting occurred is evident by the absence of older ice in ice cores drilled in southern Greenland, but the presence of ice that old in cores drilled in northern Greenland. Beach horizons on remote islands that are located a few meters above present sea level appear to confirm that a comparable amount of water (or perhaps even more from some loss of the West Antarctic Ice Sheet) had been added to the oceans. See "Paleoclimatic Evidence for Future Ice-Sheet Instability and Rapid Sea-Level Rise" Jonathan T. Overpeck, Bette L. Otto-Bliesner, Gifford H. Miller, Daniel R. Muhs, Richard B. Alley, Jeffrey T. Kiehl *Science* 24 March 2006: Vol. 311. no. 5768, pp. 1747–1750 DOI: 10.1126/science.1115159

[44] The very hot European summer of 2003 that led to a month-long heat wave that caused the premature deaths of tens of thousands is the type of rare event that is estimated to have become much more likely as a result of recent warming, and will become even more likely in the future (e.g., see Schär, C. et al., 2004: The role of increasing temperature variability in European summer heat waves, *Nature,* 427, 332–336.)

[45] Dai, A., K. E. Trenberth, and T. Qian, 2004: A global dataset of Palmer Drought Severity Index for 1870–2002: Relationship with soil moisture and effects of surface warming, *Journal of Hydrometeorology,* 5, 1117–1130.

[46] McKenzie, D., Z. Gedalof, D. L. Peterson, and P. Mote, 2004: Climatic change, wildfire, and conservation, *Conservation Biology,* 18, 890–902.

[47] Milly, P.C.D., R.T. Wetherald, K.A. Dunne, and T.L. Delworth, 2002: Increasing risk of great floods in a changing climate, *Nature,* 415, 514–17.

[48] A large hurricane striking New Orleans is only one example of a very damaging event. Other examples identified during the U.S. National Assessment included a storm surge into New York harbor, and the entire northeast coastline that has been spared strong hurricanes for several decades has since become increasingly developed, and susceptible to very high damage events.

[49] See IPCC Working Group I Third Assessment Report, 2001. Over the past few decades, the rate of rise is consistent with a rate that exceeds the upper end of this range, indicating that an acceleration in the rate may have begun during this period (e.g., see Rignot, E., and P. Kanagaratnam, 2005: Changes in the velocity structure of the Greenland Ice Sheet, *Science,* 311, 986–990).

[50] The full range for the IPCC estimate is about 4 to 35 inches considering the full range of all emissions scenarios and climate sensitivities, whereas the central estimate used in the text is for the average response across all climate models and emissions scenarios.

[51] Although projecting a rather significant buildup of ice on East Antarctica, IPCC's Third Assessment Report projected only very limited melting of the Greenland and West Antarctic Ice Sheets over the 21st century. Observations since publication of that report suggest that at least the Greenland Ice Sheet is likely to experience significant loss of ice as the warming builds up over coming decades.

[52] Low levees have already been installed around LaGuardia airport due to a severe storm some 50 years ago, and many additional areas are at risk. Low lying islands in the Chesapeake Bay have also been lost over recent times, more due to natural land subsidence than human-induced sea level rise, but providing an insight into the likely consequences of an acceleration of the rate of rise due to global warming. And the severe loss of coastal wetlands in the Mississippi delta region (again due mainly to other factors up to the present) provides a telling example of how important the coastal islands are for protecting communities.

[53] GAO, 2004: *Alaska Native Villages: Villages Affected by Flooding and Erosion Have Difficulty Qualifying for Federal Assistance,* Statement of Robert A. Robinson, Managing Director, Natural Resources and Environment, GAO–04–895T.

[54] It is substantially more difficult to catch a whale or seal by chasing it in open waters than by waiting for it to surface at an air hole.

[55] Pittock, A. B., 2005: *Climate Change: Turning Up the Heat,* Earthscan, London, 316 pp.

[56] Parmesan, C., and G. Yohe, 2003: A globally coherent fingerprint of climate change impacts across natural systems, *Nature,* 421, 37–42.

[57] For example, see Cox, P.M., R.A. Betts, C.D. Jones, S.A. Spall, and I.J. Totterdell, 2000: Acceleration of global warming due to carbon cycle feedbacks in a coupled climate model, *Nature,* 408, 184–187.

[58] For example, see Watson, R.T., J. Patz, D.J. Gubler, E.A. Parson, and J. H. Vincent, 2005: Environmental health implications of global climate change, *Journal of Environmental Monitoring,* 7, 834–843, and Hunter, P. R., 2003: Climate change and waterborne and vector-borne disease, *Journal of Applied Microbiology,* 94, 37S–46S.

[59] Beggs, P.J., and H.J. Bambrick, 2005: Is the global rise of asthma and early impact of anthropogenic climate change? *Environmental Health Perspectives,* 113, 915–919.

[60] For a given level of pollution, higher temperatures accelerate the rate of formation of photochemical smog.

Senator VITTER. Thank you very much, Doctor.

And, Dr. Reiter, welcome.

STATEMENT OF PAUL REITER, CHIEF, INSECTS AND INFECTIOUS DISEASE UNIT; PROFESSOR, INSTITUT PASTEUR

Dr. REITER. Thank you, Senator Lautenberg, Senator Stevens, Mr. Chairman, Members of the Committee.

I am a specialist in the natural history and biology of mosquitoes, the epidemiology of the diseases they transmit, and strategies for their control. I worked, for 22 years, for the Centers for Disease Control and Prevention, CDC, including 2 years as a research scholar at Harvard. I am a member of the World Health Organization Expert Advisory Committee on Vector Biology and Control. I have directed many entomological investigations of outbreaks of mosquito-borne disease and others, such as Ebola hemorrhagic fever. I was a lead author of the U.S. National Assessment of the Potential Consequences of Climate Variability and Change. I'm presently professor of medical entomology at the Institut Pasteur, in Paris, France.

In this presentation, I restrict my comments to my own field, to malaria, and I will want to emphasize to you four points. First of all, that malaria is not an exclusively tropical disease. Second of all, the transmission dynamics of the disease are complex, and the interplay of climate, ecology, mosquito biology, mosquito behavior, and many other factors defies simplistic analysis. It is—third, it is facile to attribute the current resurgence of the disease to climate change or to use models based on temperature to predict future prevalence. And, last, many environmental activists are using the "big talk" of science to create a simple, but very false, paradigm. Specialists, like myself, who protest this paradigm are generally ignored or are labeled "skeptics."

In the early 1990s, malaria topped the list of dangerous impacts of global warming. The disease was going to move to rich countries in the temperate regions as temperatures increased. This prediction ignored the fact that malaria was once an important cause of morbidity and mortality throughout most of the United States

and Europe, even in the period that our climatology colleagues have called the Little Ice Age. In the United States, as in Western Europe, despite a steadily warming climate, prevalence of malaria declined in the 19th century as a result of multiple changes in agriculture, lifestyle that affected the abundance of mosquitoes, their contact with people, and the availability of antimalarial drugs. Nevertheless, the most catastrophic epidemic of all time on record anywhere in the world occurred in the Soviet Union in the 1920s, with a peak incidence of 13 million cases per year and 600,000 deaths. Transmission was high in many parts of Siberia, and there were 30,000 cases and 10,000 deaths in Archangel, close to the Arctic Circle. The disease persisted in many parts of Europe until the advent of DDT. Clearly here, temperature was not a limiting factor in the distribution or prevalence of malaria.

In the mid-1990s, activist emphasis changed to the transmission of malaria in poorer countries, often referred to as "those least able to protect themselves," particularly in sub-Saharan Africa. Yet in most of Africa, temperatures are already far above the minimum required for transmission. In addition, in most sub-Saharan Africa, transmission is termed "stable," because people are already exposed to many infective bites, sometimes more than 300 per year. So, annual incidence is fairly constant. Mortality is highest in the newcomers, young children and immigrants. Those that survive acquire a partial immunity that reduces the risk of fatal illness.

In other regions, transmission is endemic, but termed "unstable," because annual transmission is variable. In these regions, the potential for epidemics is much higher, because immunity declines in periods of low transmission. Climatic factors, particularly rainfall, are sometimes, but by no means always, relevant.

In recent years, activist emphasis has shifted to highland malaria, particularly in East Africa. Despite carefully research articles by malaria specialists, there has been a flurry of articles by nonspecialists who claim an increase in the altitude of malaria transmission that is already attributable to warming and quote models that predict further increase in the next 50 years. Tellingly, these people rarely, if ever, give any detail of the views of specialists who challenge them, nor do they mention that maximum altitudes for transmission in the period from 1880 until 1945 were 500 to 1,500 meters higher than in the areas that are quoted as examples. And, in any case, highland above 2,000 meters constitutes a mere 1.3 percent of the whole continent, an area about the size of Poland, totally dwarfed by regions of stable and unstable transmission at lower altitudes.

An exasperating aspect of the debate is that this spurious science is endorsed in the public forum by influential panels of experts. I refer particularly to the Intergovernmental Panel on Climate Change. Every 5 years, this U.N.-based organization publishes a consensus of the world's top scientists in all aspects of climate change. Quite apart from what we consider to be the rather dubious process by which these scientists are selected, consensus, sir, is the stuff of politics and not of science. Science proceeds by observation, hypothesis, and experiment. The complexity of this process and the uncertainties involved are a major obstacle to meaningful understanding of scientific issues by the lay public. In reality, a

genuine concern for mankind and the environment demands the inquiry, accuracy, and skepticism that are intrinsic to authentic science. A public that is unaware of this is vulnerable to abuse.

The current increase in malaria is alarming, but the principal factors involved are deforestation, new agricultural practices, population increase, urbanization, poverty, civil conflict, war, AIDS, resistance to antimalarials, and resistance to insecticides. In my opinion, we should give priority to a creative and organized effort to stem the burgeoning tragedy of uncontrolled malaria, rather than worrying about the weather.

Thank you for the honor of having spoken here.

[The prepared statement of Dr. Reiter follows:]

PREPARED STATEMENT OF PAUL REITER, CHIEF, INSECTS AND INFECTIOUS DISEASE UNIT; PROFESSOR, INSTITUT PASTEUR

Malaria in the Debate on Climate Change and Mosquito-borne Disease

I am a specialist in the natural history and biology of mosquitoes, the epidemiology of the diseases they transmit, and strategies for their control. I worked for 22 years for the Centers for Disease Control and Prevention (CDC), including 2 years as a Research Scholar at Harvard. I am a member of the World Health Organization Expert Advisory Committee on Vector Biology and Control. I have directed many investigations of outbreaks of mosquito-borne disease, and of others such as Ebola Haemorrhagic Fever. I was a Lead Author of the U.S. National Assessment of the Potential Consequences of Climate Variability and Change. I am presently Professor of Medical Entomology at the Institut Pasteur in Paris, France.

In this brief presentation I restrict my comments to malaria, and emphasize four points:

1. Malaria is not an exclusively tropical disease.

2. The transmission dynamics of the disease are complex; the interplay of climate, ecology, mosquito biology, mosquito behavior and many other factors defies simplistic analysis.

3. It is facile to attribute current resurgence of the disease to climate change, or to use models based on temperature to "predict" future prevalence.

4. Environmental activists use the "big talk" of science to create a simple but false paradigm. Malaria specialists who protest this are generally ignored, or labelled as "sceptics."

In the early 1990s, malaria topped the list of dangerous impacts of global warming; the disease would move to temperate regions as temperatures increased. This prediction ignored the fact that malaria was once an important cause of morbidity and mortality throughout most of the U.S. and Europe, even in a period that climatologists call the "Little Ice Age." In the US, as in western Europe, prevalence declined in the 19th century as a result of multiple changes in agriculture and lifestyle that affected the abundance of mosquitoes, their contact with people, and the availability of anti-malarial drugs. Nevertheless, the most catastrophic epidemic on record anywhere in the world occurred in the Soviet Union in the 1920s, with a peak incidence of 13 million cases per year, and 600,000 deaths. Transmission was high in many parts of Siberia, and there were 30,000 cases and 10,000 deaths in Archangel, close to the Arctic circle. The disease persisted in many parts of Europe until the advent of DDT. Clearly, temperature was not a limiting factor in its distribution or prevalence.

In the mid-1990s, activist emphasis changed to transmission in poorer countries, often referred to as those "least able to protect themselves," particularly in sub-Saharan Africa. Yet in most of the continent, temperatures are far above the minimum required for transmission, and most of sub-Saharan Africa, transmission is termed "stable" because people are exposed to many infective bites, sometimes more than 300 per year, so annual incidence is fairly constant. Mortality is highest in "newcomers"—young children and immigrants. Those that survive acquire a partial immunity that reduces the risk of fatal illness. In other regions, transmission is endemic but 'unstable' because annual transmission is variable; the potential for epidemics is great because immunity declines in periods of low transmission. Climatic factors, particularly rainfall, are sometimes—but by no means always—relevant.

In recent years, activist emphasis has shifted to "highland malaria," particularly in East Africa. Despite carefully researched articles by malaria specialists, there has been a flurry of articles by non-specialists who claim a recent increase in the altitude of malaria transmission attributable to warming, and quote models that "predict" further increase in the next 50 years. Tellingly, they rarely quote the specialists who challenge them. Nor do they mention that maximum altitudes for transmission in the period 1880–1945 were 500–1500m higher than in the areas that are quoted as examples. Moreover, highland above 2000m constitutes a mere 1.3 percent of the whole continent, an area about the size of Poland that is totally dwarfed by regions of stable and unstable transmission at lower altitudes.

A galling aspect of the debate is that this spurious "science" is endorsed in the public forum by influential panels of "experts." I refer particularly to the Intergovernmental Panel on Climate Change (IPCC). Every 5 years, this UN-based organization publishes a 'consensus of the world's top scientists' on all aspects of climate change. Quite apart from the dubious process by which these scientists are selected, such consensus is the stuff of politics, not of science. Science proceeds by observation, hypothesis and experiment. The complexity of this process, and the uncertainties involved, are a major obstacle to meaningful understanding of scientific issues by non-scientists. In reality, a genuine concern for mankind and the environment demands the inquiry, accuracy and skepticism that are intrinsic to authentic science. A public that is unaware of this is vulnerable to abuse.

The current increase in malaria is alarming, but the principal factors involved are deforestation, new agricultural practices, population increase, urbanization, poverty, civil conflict, war, AIDS, resistance to anti-malarials, and resistance to insecticides, not climate. In my opinion, we should give priority to a creative and organized effort to stem the burgeoning tragedy of uncontrolled malaria, rather than worrying about the weather.

The Lancet Infectious Diseases, Vol. 4, June 2004

Reflection & Reaction—Global Warming and Malaria: a Call for Accuracy

For more than a decade, malaria has held a prominent place in speculations on the impacts of global climate change. Mathematical models that "predict" increases in the geographic distribution of malaria vectors and the prevalence of the disease have received wide publicity. Efforts to put the issue into perspective [1–5] are rarely quoted and have had little influence on the political debate. The model proposed by Frank C Tanser and colleagues [6] in *The Lancet* and the accompanying Commentary by Simon Hales and Alistair Woodward [7] are typical examples.

The relation between climate and malaria transmission is complex and varies according to location,[2] yet Tanser et al base their projections on thresholds derived from a mere 15 African locations. Slight adjustments of values assigned to such thresholds and rules can influence spatial predictions strongly.[8] The authors invest considerable effort in assessments of the sensitivity of their model, at the expense of defining the internal sensitivities of their thresholds and rules. The predictive skill of their model is low (63 percent sensitivity, 95 percent CI 61–65 percent) but they consider projections acceptable if prevalence is projected "to within a month" (presumably +/− 1 month?), thereby biasing their model toward success. A model covering an entire year in a parasite-positive site would always be correct, although in such areas it would be relatively insensitive to climate. By contrast, sites in which transmission is seasonal would provide a more reliable test of accuracy, but estimation is more difficult because climate sensitivity is greater. Furthermore, because parasite clearance in communities is not instantaneous,[9] spot samples of parasitaemia on survey dates are not a suitable indicator of the duration of the transmission season. Last, "person/months" are unsuitable as a measure of transmission: an extension of season from 1 to 4 months will have more impact than from 10 to 12 months. According to their model, an extension of transmission from 11 to 12 months results in 10^6 more person/months in a population of 10^6 people, whereas an extension from 1 to 5 months gives the same increase in a population of 250,000.

What Tanser and colleagues have modelled is merely the duration of the transmission season, which they interpret as "heightened transmission" and increased incidence. A greater failing is their reliance on "parasiteratio studies." The relations between transmission season and parasite prevalence, and parasite prevalence and clinical disease, are unclear but unlikely to be linear. Moreover, they use 1995 data for human populations, although these are projected to double by 2030. In addition, the proportion living in urban areas—with a specific climate [10] and orders of magnitude less malaria transmission [11, 12]—is projected to rise from 37 percent to 53

percent.[13] For all these reasons, we do not accept the model as a "baseline against which interventions can be planned."

It is regrettable that many involved in this debate ignore the rich heritage of literature on the subject. For example, in 1937, in his classic textbook,[14] L W Hackett stated: "Everything about malaria is so moulded and altered by local conditions that it becomes a thousand different diseases and epidemiological puzzles. Like chess, it is played with a few pieces, but is capable of an infinite variety of situations." A pressing question in Hackett's time was the changing distribution of the disease in Europe. On the role of climate, he wrote: "Certainly, climate lays down the broad lines of malaria distribution . . . Nevertheless, although this is a very simple and plausible explanation . . . even the early malariologists (sic) felt that there was something unsatisfactory about it . . . malaria has not so much receded as it has contracted, oftentimes toward the north . . . Thus in Germany it is the northern coast which is still malarious, the south is free . . . There is, therefore, no climatic reason why (malaria) should have abandoned south Germany or the French Riviera."

We quote Hackett because we feel that the classic components of science—unbiased observation and systematic experimentation—cannot be sidestepped with models that omit many of his chess pieces. Yet Hales and Woodward[7] begin by stating: "The present geographical distribution of malaria is explained by a combination of environmental factors (especially climate) and social factors (such as disease-control measures)." In our opinion, "even the early malariologists" would surely disagree: much of the decline of malaria in Europe took place without control measures during a period when the climate was warming.

The text by Hales and Woodward that follows displays a lack of knowledge. Thus, "Most people at risk of malaria live in areas of stable transmission . . . " is simply wrong. It is true that in many parts of the world malaria is termed "stable" because transmission remains relatively constant from year to year, the disease is endemic, the collective immunity is high, and epidemics are uncommon. However, in many other regions, the disease is endemic but "unstable" because annual transmission varies considerably, and the potential for epidemics is great. Climatic factors, particularly rainfall, are sometimes, but by no means always, relevant.[15]

Again, "On the fringes of endemic zones, where transmission is limited by rainfall . . . there are strong seasonal patterns, and occasional major epidemics" is also wrong. In many regions, far from any "fringes," malaria is endemic, stable, but highly seasonal. For example, in semi-arid regions of Mali, transmission is restricted to the rainy season, from July to September. The same 3 months constituted the transmission season for *Plasmodium falciparum* in Italy before it was eliminated.[16] Paradoxically, in parts of the Sudan, rainfall is restricted to a month at most, but malaria is transmitted throughout the year. Female *Anopheles gambiae* survive severe drought and extreme heat by resting in dwellings and other sheltered places.[17] Blood feeding and transmission continue, but the mosquitoes do not develop eggs until the rains return. This phenomenon, termed gonotrophic dissociation, is remarkably similar to the winter survival strategy of *Anopheles atroparvus,* the principal vector of malaria in Holland until the mid 20th century.[16]

By contrast, malaria is unstable in many regions that normally have abundant rainfall, and epidemics occur during periods of drought. An illustrative example is the catastrophic 1934–1935 epidemic in Ceylon (now Sri Lanka), estimated to have killed 100,000 people.[18] Worst hit was the southwestern quadrant of the country, where average annual rainfall is greater than 250 cm, and malaria was endemic, but unstable and relatively infrequent. The dominant vector, *Anopheles culicifacies,* breeds along the banks of rivers and tends to be scarce in normal years. In the years 1928–1933 there was abundant rainfall, river flow was high, *An culicifacies* was rare, and the human population was exceptionally malariafree. However, after failure of two successive monsoons, the drying rivers produced colossal numbers of *An culicifacies,* and the resulting epidemic was exacerbated by the low collective immunity. In the drier parts of the island, where *An culicifacies* was dominant but transmission was more stable, immunity protected the population from the worst ravages of the disease.

Hales and Woodward state that "the underlying problem" of the future "extension of seasonality" of malaria is "pollution of the atmosphere", and call for rich countries to "recognise their obligations to the poorest by substantially reducing fossil-fuel consumption." We understand public anxiety about climate change, but are concerned that many of these muchpublicised predictions are ill informed and misleading. We urge those involved to pay closer attention to the complexities of this challenging subject.

Paul Reiter, Christopher J Thomas, Peter M Atkinson, Simon I Hay, Sarah E Randolph, David J Rogers, G Dennis Shanks, Robert W Snow, and Andrew J Spielman.

PR is professor of medical entomology, Institut Pasteur, Paris, France; CJT is senior lecturer in spatial ecology and Wolfson Institute fellow in health and environment, School of Biological and Biomedical Sciences, University of Durham, UK; PA is professor of geography, University of Southampton, UK; SIH is a Wellcome Trust research fellow, SER is professor of parasite ecology, and DJR is professor of ecology, Department of Zoology, University of Oxford, UK; GDS is at the U.S. Army Centre for Health Promotion and Preventive Medicine, MD, USA; RWS is professor of tropical public health, University of Oxford; AJS is professor of tropical public health, immunology and infectious diseases, Harvard School of Public Health, Boston, MA, USA. SIH and RWS are also at the KEMRI Wellcome Trust collaborative programme, Kenya.

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Other Attachments

These articles are in committee files and can be found at their respective websites:

Climate Change and Mosquito-Borne Disease, Paul Reiter, Environmental Health Perspectives, Vol. 109, Supplement 1: Reviews in Environmental Health, 2001 (Mar., 2001), pp. 141–161.

http://www.pubmedcentral.nih.gov/picrender.fcgi?artid=1240549&blobtype=pdf.

From Shakespeare to Defoe: Malaria in England in the Little Ice Age, Paul Reiter

Emerging Infectious Diseases, Vol. 6, No. 1, January–February 2000
http://www.cdc.gov/ncidod/eid/vol6no1/reiter.htm

Senator VITTER. Thank you very, very much, Doctor. I'll kick off the questioning.

Dr. Corell——

Dr. CORELL. Yes.

Senator VITTER.—I wonder if you could put up one of your first slides, which was the temperature chart, because I'm trying to understand it, in part, by——

Dr. CORELL. Sure.

Senator VITTER.—comparing it to Dr. Armstrong's figure 1. Are you familiar with Dr. Armstrong's——

Dr. CORELL. I am not——

Senator VITTER.—slide?

Dr. CORELL.—but I'd be happy to have a look at it. Yes, OK. I now know what——

Senator VITTER. Right. Your——

Dr. CORELL. This——

Senator VITTER.—chart basically goes back to——

Dr. CORELL. This is 2,000 years.

Senator VITTER.—2,000 years. Dr. Armstrong's figure 1 is much more long term, I think.

Dr. CORELL. That's correct.

Senator VITTER. It goes back 400,000 years.

Dr. CORELL. Right.

Senator VITTER. And so, I guess the comparison—the conclusion from the comparison is—and correct me if I'm wrong—that the Earth has experienced similar temperature levels to the present day, but much further back than 2,000 years.

Dr. CORELL. That's correct. And I would say it's the CO_2 that is way above the record, certainly in the record that's in his testimony, but there are several papers that suggest that we have not had these CO_2 levels for 25 million years.

Senator VITTER. Right. And his chart also suggests that, because if——

Dr. CORELL. Right.

Senator VITTER.—you're looking at it——

Dr. CORELL. That's——

Senator VITTER.—his chart of CO_2 and CH_4, they're——

Dr. CORELL. Are well——

Senator VITTER.—way beyond——

Dr. CORELL.—well beyond the——

Senator VITTER.—anything in the last 400,000 years. And that——

Dr. CORELL. And——

Senator VITTER.—provoked my question——

Dr. CORELL. Yes, about——

Senator VITTER.—which is——

Dr. CORELL.—the lead-lag issue.

Senator VITTER. Right.

Dr. CORELL. Let me say a word or two about it and go to another slide here, if I can, and that's this one. As this imbalance of heat comes into the system, and the ocean observe it—absorbs it, it's

going to re-radiate that and heat—and reheat the atmosphere. But this out-of-balance is due to the CO_2 level being much higher, creating the greenhouse effect. And so, there's—during a time when we have both natural variability and human-induced variability, or human-induced warming, during that time the temperature is going to lag behind the rise in CO_2. Do you follow that, from this——

Senator VITTER. Now, why is that different from a period where it's a purely natural process?

Dr. CORELL. Because—well, several reasons. One, there's a much slower rate of warming occurring in—during the natural process period. And, quite frankly, if you look at this 400,000-year record, it's pretty hard to sort out the lead-lag relationship. In fact, some will argue that it—sometimes temperature leads the CO_2 and other times it lags the CO_2, and that's probably due to a bunch of—a whole group of natural processes. A lot of them are the wobbling and the precessions of the planet and so on. But what I want to make—the difference is that we are in a region now where we have clearly natural variability, and, on top of that, we have the human-induced increase in CO_2, and that human-induced in CO_2 is likely to cause the temperature to lag behind the CO_2 rise.

So, the answer to your question, in my judgment, is that we are going to see a continued rise in temperature. Most recent meeting in the U.K. held by John Shellnhuber and the group on the dangerous intervention issue, concluded that as we sit here, we're likely to see 2 to 3 degrees of warming, Centigrade, during this coming century. So, whether—we definitely will have a rise in temperature, given the rate at which CO_2 is increasing today.

Senator VITTER. Dr. Akasofu, do you have any reaction or comment?

Dr. AKASOFU. No, on this particular point, because as Dr. Corell mentioned, all the changes are going on. Climate change is going on, definite. No question about that. And the only thing we are trying to find is which portion is natural, which is manmade.

Senator VITTER. Right.

Dr. AKASOFU. From our study, we—the—we cannot tell.

Senator VITTER. Right.

I want to go to Dr. Akasofu's figure 1, which is really interesting to me. His basic explanation of the dip in both Arctic and the smaller dip in global temperature between 1940 and 1970 is that you have major natural factors, as well as manmade. What would be your explanation, Dr. Corell?

Dr. CORELL. Well, I think there are times when a—the—in this early part of the rise in temperature, where the natural variability can override. And we will see—I think the general consensus of the literature is that that relative cooling—relative cooling that occurred in—as Dr. Akasofu has pointed out—has—was due to a natural variability factor. But now I think we can see from the record, certainly in the last half a century, that the IPCC and much of the literature will indicate that the predominant factor of the warming is coming from human-induced CO_2 contributions to the atmosphere.

Senator VITTER. How do they reach that conclusion? How do they parcel out natural versus human?

Dr. CORELL. Well, one way to do it—there are several—one is to take your models—and I would like to talk a little about the models, because you asked a very good question about that—and ask yourself, How could we get the temperature that we have today? And we have a pretty good idea of solar variability over the last 50 to 100 years. We have a clear idea of what volcanic eruptions are. Those are—you know, those are cooling effects. In other words, we have a pretty good idea of the major contributing factors. If you try to get the temperature that we have today without the human-induced factor, you just can't get there. And there have been numerous papers that do this.

Now, we're talking at the global scale. And I think——

Senator VITTER. May I interrupt for a second?

Dr. CORELL. Yes.

Senator VITTER. Why can't you get there, since, historically, Earth has been there?

Dr. CORELL. Well, the conditions of the past at which it got there were quite different than the ones we have today. I mean, there are times when we've had much warmer regions of the Arctic there. You know, we had mastodons running around in a much warmer—a much warmer set of conditions.

What we're talking about here is, What's changing the conditions now, over the last, well, let's say 2 and a half million years, when we have had the glaciation periods with all these cycles occurring? During that time, we could not get to the temperatures we've gotten today—I mean, the CO_2 and temperatures we've got today—without having CO_2 being put into the atmosphere by humans.

Senator VITTER. Well, again, doesn't Dr. Armstrong's figure 1 suggest otherwise with regard to temperature, not CO_2?

Dr. CORELL. Well, he's not only talking about—Dr. Armstrong's—yes. Try me again. I was thinking of Dr. Akasofu's question.

Senator VITTER. No, no, that other figure——

Dr. CORELL. Oh, I——

Senator VITTER.—the one——

Dr. CORELL.—I know which one you're talking—I just misunderstood——

Senator VITTER. Doesn't that——

Dr. CORELL.—your question.

Senator VITTER.—suggest, contrary to what you just said, that you can't get there otherwise with regard to temperature, not—I mean CO_2 levels, clearly——

Dr. CORELL. CO_2, methane——

Senator VITTER.—all-time high——

Dr. CORELL. Right.

Senator VITTER.—nothing. But temperature level is not, at least yet.

Dr. CORELL. At this stage, we're at about the level—the maximum levels we've seen during the glacial period of the last million or 2 million years, that's correct. But what I'm suggesting is that we already know there's more temperature buried in the ocean to come out from CO_2 already put in the atmosphere by humans during the past 10, 20, 30 years, so that the future——

Senator VITTER. Well, but that is——

Dr. CORELL.—will be warm.

Senator VITTER.—that conclusion assumes that CO_2 is driving—the single factor or predictor.

Dr. CORELL. Well, I think the physics on that is pretty clear, that CO_2 and the greenhouse gases do trap the energy between the upper atmosphere and the ground, and warm the planet. I think that's—the physics on that's clear.

I'm maybe not getting your point, sir.

Senator VITTER. Well, again, it seems to me, in terms of the historical record, you're sort of assuming that CO_2 is the perfect predictor and overrides anything else.

Dr. CORELL. Well, I think if you do the physics on CO_2 and the other greenhouse gases, they will trap the energy between the upper atmosphere and the ground, and will warm the planet. And what is clear to us now is, the ocean has enough information—enough heat in it to warm the planet beyond anyplace we have been over the last, say, 400,000 years.

Senator VITTER. Dr. Akasofu, obviously the Arctic is an extreme case compared——

Dr. AKASOFU. Yes.

Senator VITTER.—to global situations.

Dr. AKASOFU. That's correct.

Senator VITTER. Now, that could suggest that it's the perfect place to study, because it is—shows a heightened level of trends that are global, or it—maybe it could suggest the opposite, that it's sort of an anomaly. What's your conclusion about that basic question?

Dr. AKASOFU. It goes—the Antarctic, as you said, is an signal magnitude or amplitude is at least three times bigger. So, so much easier to study. And, furthermore, what really—in this latitude, you don't see .6 degree temperature change what's happening, but Arctic, you can see all kinds of——

Senator VITTER. Right.

Dr. AKASOFU.—climatic—climate changes going on. So, the Arctic is, to me, the place we should study. That's—there is no disagreement with——

Dr. CORELL. No, no——

Dr. AKASOFU.—Dr. Bob Corell, yes. But the—Dr. Corell says yes, physics of the CO_2 is greenhouse gas. Our question is, quantitatively, how many degrees, and where? And the observations show that the actual largest, most prominent warming taking—that was taking place in the continental Arctic. But somehow the IPCC computer could not produce that. And that means, to me, it's something else. And we found that it is something else, not the greenhouse effect. So, we have to be very careful here.

Senator VITTER. I'm glad you mentioned that, because it goes back to some of the testimony from the first panel, where they suggested that some of the very recent work, including a publication in *Nature* very recently, fine-tuned some of the climatic models in such a way that it was very predictive, looking back to what we have measured historically. Can you react to that?

Dr. AKASOFU. Sorry, I don't think so at this time. I—our interest is try to understand the increase from 1920 to 1940——

Senator VITTER. Right.

Dr. AKASOFU.—and then the decrease from 1940 to 1970. Unless we understand that, we don't think we understand the increase from 1970 on.

Senator VITTER. Right.

Dr. AKASOFU. Yes.

Senator VITTER. Let me ask it a different way. How good and perfected do you think the current climatic models are, in terms of temperature prediction, if you test it against that bit of history?

Dr. AKASOFU. I believe that there are all kinds of complexities there, but the general pattern, to me, that computers should be able to produce—I mean, we have advanced so much in our simulators, all kinds of a major supercomputers working, so I trust that, at least, you know, some aspects should be—you know, computer should reproduce. And if the computers cannot reproduce—and, you know, that was the basis for the Kyoto Protocol.

Senator VITTER. Right.

Dr. AKASOFU. And if you say the computers are no good, then we have to abandon the Kyoto Protocol, too. So,——

Senator VITTER. Right.

Chairman Stevens?

The CHAIRMAN. Thank you.

Dr. Akasofu, at your request we authorized funding for further temperature measurements in the Arctic Ocean over the—what, the last 3 years? How many years?

Dr. AKASOFU. Yes.

The CHAIRMAN. And there—have you had any tentative conclusions from those temperatures as to whether there is noticeable change now, as far as the temperature of the Arctic Ocean?

Dr. AKASOFU. Yes. The—what's happening is that the warm North Atlantic water is intruding into the Arctic Ocean, and we are tracing this water. It's moving around Siberian coast, and then moving toward Alaska. So, although it's a very complicated thing, but suddenly tremendous heat is coming from the North Atlantic into the Arctic Ocean, which is, I'm sure, the partial reason for the ice melting there.

The CHAIRMAN. And is that in any way related to the recent intensity of the sun's heat, as far as the Atlantic Ocean is concerned?

Dr. AKASOFU. That, I can't tell. We just learned that—in the last paper, that as much as 30 to 40 percent of temperature increase could have been due to just the solar output increase. But we have to now go back and look at the computer modeling and put it in that and see if that will warm up North Atlantic or not. We have not done that yet.

The CHAIRMAN. And this—we have your statement, and figure 6 showing the distribution of that Atlantic water, the so-called Atlantic oscillation. How long has that been going on, do you know?

Dr. AKASOFU. Oh, as far as we determine, you know, it's at least 50—accurately, the last 50–60 years over good data—what we call NAO, North Atlantic oscillation, intensity changes, and we know that.

The CHAIRMAN. Well, is that warming of the Arctic Ocean related to some of the change we see in our State now, as far as the permafrost and basic change in the climate?

Dr. AKASOFU. OK, that's—our scientists have—different scientists have a different point of view. The continental portion of warming, they think that could be something else. But the—they are not sure yet.

The CHAIRMAN. By that, you mean what's happening in the Arctic Ocean could be both natural and manmade.

Dr. AKASOFU. I think so.

The CHAIRMAN. How long a period do we have to study that to reach a—any tentative conclusion on it?

Dr. AKASOFU. The—in the past—I think—this is my view—that people are aware that the—there are natural and manmade, both components, but not many people really spent the time to separate those out. It's very difficult. Whenever there is—we should make the effort. And we are now concentrating—some of us really working hard to do that particular job, rather than study with just the North Atlantic water coming in or something else.

The CHAIRMAN. Have you flown over the Arctic area recently?

Dr. AKASOFU. Not recently, not last year or so.

The CHAIRMAN. I took one flight—this'll be my last comment—over—coming from the West Coast, going over to Barrow, and it was pointed out to me the places where the ocean had been up far inland from where it is now. And the pilot indicated that it showed that while we think the water is rising now, it hasn't come up near where it was in years—many years gone by.

Dr. AKASOFU. Yes.

The CHAIRMAN. Now, are you able to study those other areas and see what the fluctuation has been, in terms of the Arctic Ocean's intrusion upon the Alaska part of our continent?

Dr. AKASOFU. Some of us are studying the ocean conditions or land—the features from the last Ice Age, not before that. But I think our people are collecting lots of data from during the last age, can see the major changes. And also even during a little ice age we had from 1300 to 1800, some major changes in terms of glaciers advance and retreat.

The CHAIRMAN. I don't know if my colleagues had a chance to read the statement you've got—that you've submitted, but very clearly I take it that the impact that you're trying to leave with us, is, we don't know enough yet to make a judgment as to what part of this is manmade and what part is natural.

Dr. AKASOFU. I think I agree with Dr. Armstrong. We are trying, trying. This is very hard. And perhaps IPY, International Polar Year, when some scientists concentrate on this, we may make good progress.

The CHAIRMAN. Thank you very much.

Senator VITTER. Thank you.

Senator Lautenberg?

The CHAIRMAN. I want to thank the others, too, also, but I have to go to a meeting. I don't want to prolong this right now.

Senator LAUTENBERG. Mr. Chairman, I'm a little confused here with something—some of the things that are said. And I ask Dr. Akasofu, Are you aware of any peer-reviewed science study that's said—or asserted that the present warming in the Arctic or globally is entirely due to human-caused global warming?

Dr. AKASOFU. It's—I believe that is more of the press takes that view, but most scientists agree that there are two components, those manmade——

Senator LAUTENBERG. I understand that, sir. I just want to be sure, because as I read your paper I had the—I drew the understanding that you ascribe most of this to human-caused global warming, and that the natural phenomena, the natural changes that are caused, are not something to be as concerned about. And now you do say there's a division, that there—it—the—both areas result in these changes that we're seeing. The changes are obvious. You've confirmed that in your——

Dr. AKASOFU. Yes.

Senator LAUTENBERG.—statement.

Dr. AKASOFU. Right. No question.

Senator LAUTENBERG. Yes.

Dr. AKASOFU. Yes. Dr. Corell described it beautifully, those changes.

Senator LAUTENBERG. Yes.

Dr. AKASOFU. The question is, How much is due to——

Senator LAUTENBERG. Yes. How much, Dr. Akasofu, would you—do you think that we ought to get after those things that we identify as caused by human existence, CO_2? Is that largely caused by human activities, or is that—is there any of that, that comes from natural——

Dr. AKASOFU. OK. In science—in scientific methodologies, we assume, say, it is due to carbon dioxide, and then the—we use a supercomputer—supercomputer behave like virtual Earth. We put in CO_2 into, and then calculate the result.

Senator LAUTENBERG. Yes.

Dr. AKASOFU. And if the results agree with the observations, then that is the way to confirm that——

Senator LAUTENBERG. Yes, I——

Dr. AKASOFU.—it's CO_2.

Senator LAUTENBERG. Forgive me for——

Dr. AKASOFU. There is, so far——

Senator LAUTENBERG.—interrupting, but——

Dr. AKASOFU. There is, so far, no confirmation yet.

Senator LAUTENBERG. Well, but—so, should we not intervene in trying to reduce the human contribution to——

Dr. AKASOFU. No, I am not saying that at all.

Senator LAUTENBERG. No, I know you're not saying that, but—I'd like you to say that. But the thing is that—at what point do you say—"you," I'm saying, generic "you," lots of people—say, "Hey, we know that this is a phenomena that portends bad things for the human race." And if we agree with that, then I say, "Well, what—at what point do we ask the politicians"—Dr. Reiter said something about political hay being made of this, as opposed to science. I'm going to ask you about that. And so, at what point, Dr. Corell, does the alarm sound loudly enough that says, "Hey, let's stop destroying our forests, let's stop emitting these carbon dioxide chemicals—or results into the air"? At what point do we take care to join in the protection of our environment and our lives?

Dr. AKASOFU. There is no question that we have to—I don't think we can ever reduce the total amount of carbon dioxide in the air, but we should try to reduce the rate of increase. China is——

Senator LAUTENBERG. Dr.——

Dr. AKASOFU.—coming, India is coming——

Senator LAUTENBERG. Thank you.

Dr. AKASOFU. Yes.

Senator LAUTENBERG. Dr. Corell?

Dr. CORELL. Yes, I think it's pretty clear from the assessments that the scientific community have put together, a variety of them, whether it be IPC, national assessment of the U.S. or Canada or other countries around the world, our recent Arctic assessment clearly indicates that it's time for action. And let me tell you why I believe so strongly it is time for action.

If we were wise enough to take our CO_2 and reduce it, like, over the next 100–150 years, OK—this is the result of some model studies—it would take the planet about 200 years for the CO_2 to stabilize at some higher level, 700 or so, something—some number, quite a bit higher than we are today. It'll take another 200 years, roughly, for the temperature to stabilize. So, we're talking about 3- to 500 years before the planet's stabilized. This is if we act, and it takes us 100 to 150 years to bring things down.

The real sleeper is that sea-level rise will continue for probably 1,000 or more years, with those increased temperatures that are a result of the higher levels of greenhouse gases. So, if that's so—and we believe strongly, it is; this is IPCC results that came out of our study, as well—it seems logical that you ought to move that action time shorter to lower those temperature rates and to reduce the time for the stabilization to occur.

So, I think the conventional wisdom within the scientific community is that we know enough now to take appropriate action. That's a political issue. That's an issue for you and others like you, to figure out how you take those steps, but we're trying to suggest to you, it is timely, and it is now that such steps should——

Senator LAUTENBERG. Sure.

Dr. CORELL.—be taken.

Senator LAUTENBERG. Yes, a recommendation is being clearly made from the abundance—from the gathering of science—scientific knowledge that we have now, that we ought to get on with changing the pattern of what we see overtaking us, by intervening in the emission of CO_2—and, again, I use deforestation as the example, but lots of things that we do as humans that violate the chances for our environment to succeed, as we know it.

Dr. CORELL. Agreed.

Senator LAUTENBERG. Dr. Reiter—unfortunately, we're going to have to rush through this—you use the equivalent of the canary and the coal mine, in terms of malaria. And you know what that example, traditional——

Dr. REITER. Oh, they were British mines, I think.

[Laughter.]

Senator LAUTENBERG. Yes. So, you say that, and you don't like the environmental activists using big talk of science to create simple, but false, paradigms. We have every right—and I'm not talking as a United States Senator, and I'm talking about every right as

a human being—to take what we hear and take what we read and take the evidence that we see in front of us, all kinds of indications that this world is a less accommodating place than it was. And you—your closing comment, I think, is one of the, kind of, more interesting, worrying about the weather, "Ah, don't worry about that." You're right, why worry about a Katrina or a tsunami or frequency of these storms and the ferocity of these storms, when malaria is not shown to be anything that's produced that's essentially or totally a tropical disease or—it doesn't indicate any real growth over the years, with substantial reductions, but a little spike. And you're a scientist, and a very well educated one, but I think worrying about the weather, other than to—buying an umbrella or something like that, is probably a good idea. And so—and it's consistent with what we want to do here; and that is, gather information that helps us spur some activity. That's what we do. We're—we have the political muscle to do things, unless it's counteracted by structure of government.

You know, I think that, you know, we have a suggestion now that as—that gas prices are so high that we ought to break environmental rules that exist now and get on with it, getting that gasoline price down. As they say in my old schoolyard—I grew up in a tough area—"It ain't gonna happen that way," I can tell you. We can violate good environmental activities, and it's not going to affect what we—what happens in gas prices. We're—there's a whole other thing there.

And what we do here, as legislators, is react to things. We rarely ever do anything that's creative in major magnitude that's induced by other than a reaction to a—what happens. And I was listening to these discussions about the hundreds of years away, and—but we have an obligation to worry about those hundreds of years away.

And when I see a report put out for the Navy that says, "The Navy's got to be prepared in the second half of this century to fight off refugees seeking higher land," we know now people will get into tire tubes and chance trips with shark-filled waters to get to this great country of ours. But if people are going to be deluged by water—and we're talking about places that are not so distant from us, not necessarily Bangladesh, which is a—threatened, but the Netherlands and places like that.

And, Mr. Chairman, you've experienced the worst of what happened in the—when a storm hits and the water rises above your capacity to contain it. So, we ought to get on with our task. And I would hope that the scientists would scare us a little bit and not let—let us feel too comfortable about, "Well, natural causes." If there is a natural cause, there's a natural cause, but if there isn't, then we ought to do something about that share of it.

Dr. REITER. May I answer your question?

Senator LAUTENBERG. Sure.

Dr. REITER. First of all, I didn't mean to be flippant about the importance of the weather. What—and, again, I chose my own field as an illustration of problems of public health.

I'm very glad that you say that I'm well educated. I like to think I could be better educated.

What I would urge you to do—and I would urge all of those who are interested, at least in the health aspects of this debate—is to look up the credentials, the scientific credentials of the principal exponents—proponents, I'm sorry—proponents of this disastrous situation, and compare them to the credentials, scientific credentials, of those who are essentially saying, "Well, wait a moment. What are you saying? We don't have—we don't have the evidence for this." And if you look—I mentioned the IPCC, and I know that others have talked about the IPCC in a different way. I can only talk in the field of health. I can tell you, please look at——

Senator LAUTENBERG. So, you're critical of the IPCC.

Dr. REITER. Yes. Well, hang on. May I finish? If you look at the credentials of the lead authors——

Senator LAUTENBERG. Dr. Reiter, I must leave. And I don't want to leave an empty chair and be disrespectful. So, I would say this, that when the National Academy of Sciences contributes their view, that there is pretty solid evidence there, and other distinguished science groups. I say, "Well, OK, you might be wrong."

Forgive me, I've got to go.

Senator VITTER. Dr. Reiter, please finish up. I'm all ears.

Dr. REITER. Well—no, I don't want to continue about the IPCC—that's a quite different issue—except to suggest that you look at the credentials of the lead authors. You will find that none of them—neither of them have any credentials in the field of public health. And if you look back to the reports of 2001 and 1995, you will see exactly the same. You will find that there are people there whose previous studies were on motorcycle crash helmets and the effects of cellular telephones on brain cancer. These are issues that really may be important, but, when we are talking about public—important public-health issues, we need to go to the people who specialize in public health.

Senator VITTER. Actually, I was going to ask you about the IPCC, because I find it very interesting that both you and Dr. Corell refer to it, in, of course, completely different ways. I'd just ask you to follow up on your comments and your testimony. The IPCC exercise, how driven do you think it is by scientific rigor or politics and ideology?

Dr. REITER. First of all, again, I can only speak for the health chapter, Chapter 8. In my opinion, we have to remember that this is the Intergovernmental Panel on Climate Change. Those—you may notice that I added to my dossier for you a paper—an article that nine of us, who consider ourselves leading experts in our field, published in The Lancet. We called it, "A Call for Accuracy: Malaria and Climate Change." And, basically, none of us are on the panel—are on the Chapter 8 Panel. I can also tell you that I know of certain very highly respected persons that were nominated by the U.S. Government for lead authorship in Chapter 8 and were turned down in favor of people—one person who has not a single scientific article written in the whole career.

So, I think, at least in my field, yes, there is a strongly biased selection of people, and I know, also, from people who have been expert reviewers, that the expert—the review system is very interesting. Normally in science, review is by anonymous peer review. And the—in the IPCC, it is the opposite. It is by nonanonymous

peer review. The expert reviewers discuss with the authors and come to so-called consensus. Now, when we did the U.S. Government evaluation in—about 5 years ago, it was the opposite, or, rather, those of us—well, let me go on to what the real opposite was. The discussions were public domain. You can actually find out what those discussions were by looking on the Web. You cannot see what the criticisms were of the authorship in the first and the second draft of the health chapter. In other words, what I feel is that a major investigation of the means by which the conclusions of the IPCC, at least in my field, are drawn, is overdue.

Senator VITTER. Is it fair to say, then, that some of the traditional methods brought to scientific publication, like anonymous peer review, are abandoned in that U.N. process?

Dr. REITER. Well, it certainly isn't anonymous peer review. And it is very hard for those of us who are in this field—as I mentioned before, it is very hard for us to make some sort of scientific comment without either being ignored or being called "skeptics," in a rather derogatory way.

What I tried to say, policymakers like yourself increasingly depend on science for making policy. And, by the way, scientists depend a great deal on policymakers for their living. But in a democratic society, policymakers respond to the public conceptions of these issues. We scientists are not really very good at essentially communicating with the public; or, rather, I think the public doesn't quite realize the way—the difficulty there is in conveying the way that science operates.

Public conceptions are essentially shaped by the press. We scientists also find it very difficult to deal in a scientific way with the press. The press normally picks up on those things, as is obvious, that have, perhaps, the most extreme implications on life on Earth.

On the other hand, those people who would like to speak on behalf of scientists, whether they are scientists or not, have a very much greater influence on the press, on public conceptions, and, therefore, on policymaking. And this, I feel, is not only in this field of climate change, but it also applies to many other issues that have become controversial or have become important in the way that policy is made.

Senator VITTER. Thank you very much.

Thanks to all of you. This has been quite significant and lengthy and wide-ranging hearing. I appreciate all of your testimony and participation. Again, several of you came from quite a distance, we deeply appreciate that.

And, with that, the Subcommittee hearing is adjourned.

[Whereupon, at 5 p.m., the hearing was adjourned.]

APPENDIX

PREPARED STATEMENT OF HON. DANIEL K. INOUYE, U.S. SENATOR FROM HAWAII

In just the last few months a number of alarming new studies have come out on the projected and observed effects of climate change. These studies—and the testimony today—report that some projected climate change impacts are already occurring, and these changes are taking place at a faster pace than predicted.

Latest estimates foresee a warming of the Earth's temperature of somewhere around five degrees by the end of the century. By 2100, sea levels could be several feet higher than they are now, which would have devastating effects on coastal areas, including my home State of Hawaii and the other Pacific Island nations. We have already seen the powerful destruction tsunami or severe weather can have on our low lying islands, and this damage will be magnified under the National Oceanic and Atmospheric Administration's (NOAA) projections of a one to three foot rise in sea level.

Scientists also tell us that if trends continue as projected, we will see an increase in the already alarming growth in ocean acidification and coral bleaching events. These ocean changes would have virtually irreversible impacts on the fisheries and tourism industries and thus the Hawaiian economy. NOAA tells us that it took 80,000 years for ecosystems to recover from the last mass extinction from ocean acidification.

As I have noted previously, I also have serious concerns about the Administration's efforts to suppress or downplay the findings of government scientists, particularly in this area of global climate research. It is only through broad dissemination of their research and public conversation that we can effectively tackle the causes of climate change. We must have the benefit of a full and open scientific assessment of the likely effects of climate change in the next 20 to 50 years, as already required by law. The Administration should not be avoiding and suppressing our scientists and their message, but rather listening to them attentively, and making plans to prevent dangerous interference with the climate system.

I am very interested to hear more today about how climate change is going to affect all of us, what the Administration and others think we can do to prevent the worst impacts, and what we must do to prepare for the impacts that are already unavoidable.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. DANIEL K. INOUYE TO STEVEN A. MURAWSKI, PH.D.

Question 1. There is a general scientific agreement that sea level rise is occurring at a global average rate of two millimeters per year. Sea level rise is projected to accelerate during the 21st century, with the most significant impacts in low-lying regions where subsidence and erosion problems exist. Rising sea level has worldwide consequences because of its potential to alter ecosystems and habitat in coastal regions. Sea level rise and global climate change issues in the coastal zone include:

- Higher and more frequent flooding of wetlands and adjacent shores;
- Increased flooding due to more intense storm surge from severe coastal storms;
- Increased wave energy in the nearshore area;
- Upward and land-ward migration of beaches:
- Accelerated coastal retreat and erosion;
- Saltwater intrusion into coastal—freshwater aquifers;
- Damage to coastal infrastructure; and
- Broad impacts on the coastal economy.

Dr. Murawski, in your testimony you discuss the effects of sea level rise on islands and several atolls in the Northwestern Hawaiian Islands. I am more inter-

ested in hearing about the potential impacts of sea level rise on the inhabited islands of the Pacific region.

Can you tell us about the potential for adverse impacts from sea level rise on the population centers of the Central and Western Pacific, particularly with respect to port and road infrastructure, coastal habitats, living marine resources, and vulnerability of towns and villages to extreme coastal events, like tsunamis and typhoons?

Answer. NOAA monitors sea level and uses the data to compute trends. The following table provides estimates of relative mean sea level trends based on analysis of tide gauge observations. The trends included in this table are "relative" measurements because they include both the effects of global sea level change and the local vertical land movement. The accepted range of global sea level rise by the scientific community is between 2.0 and 3.0 mm/yr.

Station	Trend	Standard Error*
Johnston Atoll	0.68 mm/yr (0.22 ft/century)	0.31 mm/yr
Midway Islands	0.09 mm/yr (0.03 ft/century)	0.31 mm/yr
Guam	0.10 mm/yr (0.03 ft/century)	0.09 mm/yr
Pago Pago	1.48 mm/yr (0.49 ft/century)	0.56 mm/yr
Kwajalein	1.05 mm/yr (0.34 ft/century)	0.51 mm/yr
Chuuk Atoll	0.68 mm/yr (0.22 ft/century)	0.09 mm/yr
Wake Island	1.89 mm/yr (0.62 ft/century)	0.35 mm/yr
Honolulu	1.50 mm/yr (0.49 ft/century)	0.14 mm/yr
Hilo	3.36 mm/yr (1.10 ft/century)	0.21 mm/yr
Mera, Japan	3.66 mm/yr (1.20 ft/century)	0.12 mm/yr
Aburastubo. Japan	3.33 mm/yr (1.09 ft/century)	0.14 mm/yr
Tonoura. Japan	0.38 mm/yr (0.12 ft/century)	0.12 mm/yr
Wajima, Japan	–0.80 mm/yr (–0.26 ft/century)	0.13 mm/yr
Xiaman, China	1.02 mm/yr (0.33 ft/century)	0.30 mm/yr

*The standard errors provide a measure of uncertainty in the computed trends.

Even with the low rates of relative sea level rise tabulated above, any increase or acceleration in the trends due to climate variability and change could have significant long-term effects on the remote ocean islands. This is because portions of many of the islands are low-lying with relatively flat topographies. Analysis of the tide gauge records from these islands show no apparent acceleration in the relative sea level trends to date.

NOAA is working with local coastal managers and stakeholders in the Pacific, through the Pacific Services Center, to improve the development and delivery of risk management-related information products and services in the Pacific. The project is called Pacific Risk Management ʻOhana (family) (PRiMO).

On a larger scale, NOAA is working with other Federal agencies on the Climate Change Science Program, which is directing a range of research to address coastal sensitivity to climate change.

URL References:

http://tidesandcurrents.noaa.gov/sltrends/sltrends_global.shtml.

http://www.csc.noaa.gov/psc/FHMPPI/.

Question 2. As you know, we had tragic loss of life in Hawaii due to a dam failure after a period of torrential rains. Does the National Oceanic and Atmospheric Administration's (NOAA) research suggest we will need to pay more attention to mudslides and infrastructure failure as the oceans warm and rise?

Answer. One need only look at Central America's experience with Hurricane Mitch in 1998, and California during the 1997–1998 El Niño event, to see the potential devastation that intense precipitation can bring to a vulnerable region and its infrastructure. More recently, loss of life and property due to heavy rains were reported in Hawaii (February to March 2006) and the northeastern United States (May 2006), and the early onset of the summer monsoon in India killed 38 people (June 2006). NOAA research indicates that warmer climates will bring higher probabilities of extreme precipitation, even in locations where average precipitation may be decreasing.[1] NOAA data show increases in water vapor as the global climate has warmed, consistent with theoretical expectations. Thus, as the oceans warm and sea level rises the compounding effects of heavy rainfall and storm surge will need to be assessed to understand their full impact on coastal infrastructure.

[1] Karl, T. R., and K. E. Trenberth, 2003. *Modern Global Climate Change.* Science, 302: 1719–1723.

Question 3. What is the range of marine ecosystem impacts that we might expect to see in the Western Pacific, and over what timeframes?

Answer. Sea level rise is compounded by subsidence on islands such as Maui and Hawaii, which have rates of relative sea level rise of 3.5 to 5 mm/yr. Impacts to marine environments in the Western Pacific could include changes in water circulation, wave dynamics, sediment production and resuspension, transport of pollutants and nutrients, and possibly larval transport. Ecosystem-based management strategies can help mitigate the effects on reef environments.

Changes to reef processes and reef distribution may occur in areas most vulnerable to changes in sea level. According to the U.S. Geological Survey, which has undertaken a study to understand and predict the response of reefs to accelerated sea-level rise, projected sea level rise will be particularly significant for low-lying coral atolls, many of which have maximum elevations of less than 5m above present sea level. Even in high island settings (*e.g.*, main Hawaiian islands and Guam), large volumes of sediment stored at or near sea level could be exhumed and transported to reefs by increases in sea level.

Coral ecosystems in the Western Pacific are also susceptible to other ramifications of climate variability and change, including coral bleaching caused by elevated sea surface temperatures and ocean acidification caused by increased carbon dioxide concentrations. There is not a strong consensus on the potential effects of climate variability and change on other coastal and marine island ecosystems. such as mangrove and seagrass ecosystems of the Western Pacific.

Accelerating Ocean Acidification

Question 4. A National Oceanic and Atmospheric Administration (NOAA) study released in April 2006 shows that rising temperatures are increasing the daily uptake of carbon dioxide by oceans. This changes the chemistry of seawater, making it more acidic, and having negative effects on corals and other marine life. NOAA oceanographers confirmed studies conducted in the 1990s showing that ocean acidification is occurring at "significantly increased rates," and say ocean chemistry is changing at least 100 times more rapidly than it has during the 650,000 years preceding our industrial era. At current levels of carbon dioxide emissions, NOAA computer models predict that oceans will continue to acidify to "an extent and at rates that have not occurred for tens of millions of years."

Dr. Murawski, the National Oceanic and Atmospheric Administration's (NOAA) recent study shows that ocean acidification is occurring at "significantly increased rates," adversely affecting water chemistry and leading to "major negative impacts" on corals and other marine life.

The National Oceanic and Atmospheric Administration (NOAA) has stated that ocean acidification could substantially alter the biodiversity and productivity of the oceans. Can you tell us when we might see the effects of ocean acidification on the biodiversity and productivity of the ocean in the Pacific islands region?

Answer. While many of the models applied to describe the projected trends in ocean acidification have centered on the Pacific Ocean, the models are not specific to the Pacific islands region and uncertainty remains regarding the precise timing and biological impacts. Recent estimates indicate roughly half of the anthropogenic CO_2 released since the industrial revolution has been absorbed by the surface waters of the world's oceans.[2] This has resulted in probably the most dramatic decrease in ocean pH for the past 400,000 years.[3] This process of ocean acidification imparts an important control on the degree to which the surface waters are supersaturated with respect to carbonate minerals (*i.e.,* saturation state), from which some marine organisms construct their skeletal structures. Studies on hermatypic corals, coralline algae, mesocosm coral reef communities and natural coral reef ecosystems have shown that the calcification of a diverse selection of organisms and natural systems correlate strongly with aragonite saturation state.

The aragonite (calcium carbonate) saturation state has already declined from pre-industrial levels by more than 10 percent in the tropics and could drop a further 20–30 percent by 2100 if CO_2 emissions continue as projected by the Intergovernmental Panel on Climate Change (IPCC)1S92a "Business as Usual" scenario (1995).

[2] Sabine. CI., R.A. Feely, N. Gruber. R.M. Key, K. Lee, J.L. Bullister, R. Wanninkhof, C.S. Wong, D.W.R. Wallace, B. Tilbrook. F.J. Millero, T.-H. Peng, A. Kozyr. T. Ono. and A. F. Rios 2004. *The oceanic sink for anthropogenic CO_2*. Science. 305, 367–371.

[3] Orr J.C., Fabry V.J. Aumont 0., Bopp L. Doney S. C., Feely R.A. Gnanadesikan A. Gruber N., Ishida A. Joos F., Key R. M., Lindsay K., Maier-Reimer E. Matear R., Monfray P., Mouchet A. Najjar R. G. Plattner G.-K,. Rodgers K.B. Sabine C.L. Sarmiento J.L. Schlitzer R., Slater R.D., Totterdell I.J., Weirig M.-F., Yamanaka Y., and Yool A. 2005. *Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms.* Nature. 437(7059), 681.

Model results based on the more conservative IPCC SRES B2 emissions atmospheric CO_2 increase scenario, together with laboratory estimates of the sensitivity of corals to ocean acidification, suggest that the waters of the Pacific islands region will may not support optimal coral calcification rates beyond approximately 2050 ±20 years.[4]

These scenarios are projections of what is likely to occur with regards to the broad oceanic changes in saturation state. However, the projections are less likely to accurately predict coastal zone conditions, where complexities can arise involving buffering by dissolution of carbonate minerals. Furthermore, the models assume an equitable biologic response to changes in saturation state while it is well demonstrated that the magnitude of the effects is not universal and varies between species and even among individual organisms within the same species.

We are only beginning to understand how rapid changes in ocean chemistry will impact marine biota. The magnitude of the effects is not universal and varies between species and even among individual organisms within the same species. It is not yet fully understood how such changes in calcification rate will impact marine ecosystems at the community scale. For example, it has been suggested that although the calcification rates of corals are expected to decrease in response to ocean acidification, organisms such as seagrasses and algae could benefit from the increased CO_2 and thereby hasten the community shift to a lower biodiversity environment. In addition to impacts resulting from ocean acidification, marine ecosystems will also respond to other climate-and human-induced stresses (e.g., increasing sea surface temperature, rising sea level, overfishing. etc.).

Studies have begun to investigate the synergistic effects of decreased saturation state and increased temperature on selected coral species. It is difficult to determine the combined effect these stressors will have, and the precise timing of any impacts. As a consequence of our current uncertainty with regards to the anticipated coastal changes in saturation state, the variability in the biological response to such changes, and the complexities of other climate change variables, we cannot be certain of the exact rates, final extent, and detailed geographic distributions of the impacts of ocean acidification. The current prevailing scientific view is that such changes will largely be detrimental to coral communities and that such changes will likely be experienced within this century.

Question 5. What will be the effects of ocean acidification on the corals and associated fisheries and tourism businesses that the Pacific islands are so dependent upon?

Answer. The full range and magnitude of the biological and biogeochemical effects of ocean acidification are still so uncertain that a reliable and quantitative estimate of the likely socioeconomic effects is not yet possible.

Question 6. What future programs or products are planned by NOAA to monitor the oceans' response to growing carbon dioxide levels and provide decision-makers with advice on mitigation options, particularly in the Pacific?

Answer. Ocean acidification is an emerging issue: hence current understanding does not offer many specific mitigation options at this time. Efforts have begun to develop observatories at select U.S. coral reefs that monitor a Reef Metabolic Index (RMI) designed to track broad changes in community-scale calcification. These observatories will expand on existing monitoring stations, remote sensing efforts, and near-reef carbon measurements to measure overall biological performance of the ecosystem. In addition, efforts have begun using satellite remote sensing to document the coastal and global long-term distribution of the phytoplankton *Emiliania huxleyi,* which is a key algal species demonstrated to exhibit sensitivity to changes in ocean pH. This kind of information will be essential for decision-makers to develop an understanding of the magnitude and extent of the changes that are occurring within U.S. coral reef ecosystems over time, and for developing and testing the effectiveness of newly developed mitigation procedures.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. FRANK R. LAUTENBERG TO STEVEN A. MURAWSKI, PH.D.

Question 1. In your written testimony you indicate that scientific uncertainties remain on how much of the observed warming is due to human activities. Given the complexity of global climate change, that past observations of the climate are uncertain, and that projections are being asked looking a century or more into the future, is it inevitable that there will be uncertainties, no matter how much research is done?

[4] Guinotte J. M., Buddemeier R. W., and Kleypas J. A. 2003. *Future coral reef habitat marginality: temporal and spatial effects of climate change in the Pacific basin.* Coral Reefs, 22(4). 551.

Answer. The short answer is that yes, there will be uncertainties no matter how much research is done because the climate system is not a completely deterministic system. Uncertainty associated with climate variability and change can have many sources, including the nature and quality of the available data: the ability of models to capture processes and their relationships (including predictability); and other factors related to the impacts of human behaviors [1] (Moss and Schneider, 2000). There is also uncertainty about the natural interactions among the various components of the climate system. Given the impact uncertainty has on our efforts to understand, communicate, and adapt to climate change, the scientific community continues to pursue this area of research and has taken steps in recent years to address the nature of uncertainty in their assessment efforts, as reflected in the U.S. Climate Change Science Program (CCSP) and the Intergovernmental Panel on Climate Change (IPCC) reports.

For example, the CCSP Synthesis and Assessment Product 5.2 is intended to further develop this topic through the synthesis, assessment, and communication of what is known about the character and magnitude of uncertainty, as it applies to climate, and to address some potential approaches to decision-making given the uncertainty. This report will address uncertainty related to decision support activities, ranging from the conduct and communication of research to the actual consideration and use of scientific knowledge and information products in decision-making.

Research is also leading to improved understanding of natural climate variability and its impacts. Current global climate models are improving our understanding of global climate sensitivity, ocean dynamics, climate feedbacks, and trends in extreme weather events and enhancing our ability to forecast climate on seasonal time scales and beyond. As models continue to improve, uncertainties in climate response will continue to be reduced resulting in a better understanding of current and future climate projections.

Question 1a. Does NOAA make decisions on many matters governing resource management (*e.g.*, fisheries management) where there are also significant uncertainties?

Answer. NOAA develops fishery management plans (FMPs) and amendments, under authority of the Magnuson-Stevens Fishery Conservation and Management Act, based upon the best scientific information available (Section 301(a)(2)). Where there are significant uncertainties, NOAA supports using a precautionary approach.

Question 1b. What metric is being used to document how much uncertainty exists and the progress being made to reduce uncertainties?

Answer. NOAA is tracking research progress in reducing uncertainty through two performance measures under the Government Performance Results Act (GPRA):

1. Reduce the Uncertainty in Model Simulations of the Influence of Aerosols on Climate, and

2. Reduce the Uncertainty in the Magnitude of the North American (NA) Carbon Uptake.

These high-level NOAA Corporate performance measures aim to track our skill in reducing uncertainty in estimates of North American carbon uptake from the atmosphere and in model simulations of aerosol impacts on climate. Improvements in measurements of carbon uptake will be important in validating carbon trading options at the regional level (*e.g.*, carbon trading markets being discussed in CA and New England). The uncertainty of NOAA estimates of North American carbon uptake has decreased each year since 2003 as the NOAA North American carbon observation network approaches completion.

Question 1c. What efforts are underway that relate one uncertainty to another and that amalgamate individual uncertainties into an overall uncertainty, determining whether an individual uncertainty is important or not?

Answer. The overall uncertainty in the uptake of carbon by the North American continent is a suitable high-level measure that represents considerable effort to identify and attribute regional sources and sinks of carbon dioxide and other related gases. Several lower-level, more specifically focused measures are used to guide our efforts. Work is currently underway to employ both vertical observations from the network and analysis modeling to generate maps of regional emissions of carbon gases. The early maps, based upon the network at this time, are promising. They suggest a very real opportunity to provide, within a few years, emission and uptake maps on spatial and temporal scales that are useful for making regional decisions

[1] Moss. R., and S. Schneider, 2000. Uncertainties, in *Guidance Papers on the Cross Cutting Issues of the Third Assessment Report of the IPCC,* edited by R. Pachauri, T. Taniguchi, and K. Tanaka, Intergovernmental Panel on Climate Change (IPCC), Geneva.

on managing carbon. As regional sources and sinks are identified and quantified, uncertainty decreases considerably. This effort is a necessary component of the North American Carbon Program, which involves a host of universities and many U.S. agencies, including NOAA, the National Aeronautics and Space Administration, Department of Energy (DOE), U.S. Department of Agriculture, U.S. Geological Survey, and the Environmental Protection Agency, among others. The goal is to build a system that can measure the transfer of carbon between land and atmosphere across the continent to vastly improve our understanding of its cycling. Subsequently, the U.S. Climate Change Science Program (CCSP) embraced this effort and a good part of its coordination is now conducted through the Carbon Cycle Interagency Working Group of the CCSP, of which NOAA is a major player. The idea was that measurements of ecosystem emissions or uptake (done or overseen by other agencies) should be verifiable with a vertical network of atmospheric observations (provided by NOAA and its partners) combined with coupled models that accounted for transport, fires, human emissions, and ocean influences. The greater understanding that comes with this effort will allow attribution of sources, lending considerable support to management and mitigation options for society.

A second benefit of NOAA's carbon effort is the potential use of satellites to detect carbon emissions and uptake. Today, satellites are incapable of measuring CO_2, with the accuracy and precision needed for such a study. However, that does not belie their potential use in the future, and their ability to provide high-frequency spatial coverage is unsurpassed. Because satellites measure total column amounts, success of satellite measurements requires a ground-based vertical network to support them. Satellites also require the calibrations of the ground based network, as sensors tend to drift, given that they operate in an inhospitable environment.

A third area where we are focused on reducing uncertainty is through our work to improve understanding of the growth, distribution, and chemistry of aerosols in the atmosphere. Unlike carbon dioxide or other long-lived greenhouse gases, uncertainty in estimating the contribution of aerosols to global warming is significant. Current information suggests that aerosols have predominantly a cooling effect, and the effect could be large. Because aerosols are not well-mixed in the atmosphere, their effect on cooling or heating depends upon their distribution, size, and chemical composition. NOAA and its partners (DOE, University of Colorado, and others) currently are developing an observational record of aerosols at key locations around the world. We also are studying aerosol and related processes in the field and laboratory to improve our understanding of their effect on climate. By using these findings to improve aerosol-climate models, we systematically reduce the uncertainty in our estimate of their overall contribution to climate.

Work is also progressing on the development of an index that separates uncertainties in climate projections into three components: (1) sub-seasonal: (2) seasonal; and (3) decadal. Once completed, this index will allow us to assess the uncertainties in climate projections for time scales ranging from days to decades.

Question 2. What studies is NOAA undertaking to determine how available information on climate change is being and can be used, and what the role is of uncertainties in decision-making?

Answer. The Regional Decision Support (RDS) program of NOAA's agency-wide Climate Mission Goal includes a focused research capability designed to address the role of climate and climate information in decision-making processes for climate-sensitive regions and sectors. The RDS effort harnesses the intellectual capabilities of NOAA and the external scientific community through a competitive grants process, and is conducted in partnership with NOAA's operational and transition activities to ensure that NOAA's climate services are well oriented to the needs and capabilities of the constituencies it serves. The RDS research effort is composed of two programs that address the use of climate information in decision-making: the Regional Integrated Sciences and Assessments (RISA) Program. and the Sectoral Applications Research Program (SARP). These programs complement and enhance each other, approaching the critical research issue of climate information for decision support from a regional and sectoral perspective. NOAA has more than a 10-year investment in research on the impacts and potential research applications associated with climate variability and change. This research has mostly been focused on shorter time scales (seasonal to interannual), but has provided useful insight into society's demand for and the potential value of climate information over multiple time scales, from intraseasonal (weeks/months) through decadal.

In addition to the RDS research effort, NOAA is leading the development and production of two Climate Change Science Program (CCSP) Synthesis and Assessment Products (SAPs) that address the use of climate information and the role of uncertainty in decision-making:

a) CCSP SAP 5.2: Best practice approaches for characterizing, communicating, and incorporating scientific uncertainty in decision-making; and

b) CCSP SAP 5.3: Decision support experiments and evaluations using seasonal to interannual forecasts and observational data. (*http://www.climatescience.gov/Library/sap/sap5-3/sap5-3prospectus-final.htm*)

NOAA supports similar work internationally by funding the International Research Institute for Climate Prediction, whose mission is to enhance society's capability to understand. anticipate, and manage the impacts of seasonal climate fluctuations in order to improve human welfare and the environment, especially in developing countries in Asia, Africa, and the Americas.

Question 2a. If any studies of this nature have been completed by NOAA, what were the findings?

Answer. Studies conducted by the NOAA RDS effort have addressed the use of climate information in a suite of diverse regions and sectors, including the following:

Sectors	U.S. Regions
Natural hazard preparedness	Pacific Islands
Agriculture and food security	Pacific Northwest
Water resource management	California
Coastal management	Southwest
Public health	Southeast (two regions)
Urban	New England
Ecosystem management	Intermountain West
Conservation	
Transportation	
Energy	

There are certain sectors where NOAA has been more active, and thus has more knowledge of the role of climate and climate information, including the nature and implications of uncertainty. Examples of such sectors include fire management, public health, water management, and natural hazards preparedness. Other sectors, such as coastal, urban, and conservation, are beginning to articulate their interest in climate. Two sector-specific examples of NOAA's work follow:

- Climate information is being used to predict pre-season fire potential for the United States. NOAA-funded climate researchers, USDA-Forest Service, and the National Interagency Coordination Center have developed a series of National Seasonal Assessment Workshops to enhance fire preparedness, prescribed fire management, and awareness of the connections between climate and fire. Participants synthesize and analyze climate, forestry, and fire science information to predict fire potential for the upcoming fire seasons.
- Climate information is being used to a limited extent by municipal water managers. Through an ongoing NOAA-supported study, we have found that municipal planners use a diverse set of climate information, including climate/water indices, and some use paleo data to inform thinking about long-term climate. Some municipal water providers create their own system-specific indices to determine what might trigger water supply and demand issues for their water system.

Specific findings of the RDS studies can be found on the websites for the RISA and SARP activities: *http://www.climate.noaa.gov/cpo_pa/risa/* and *http://www.climate.noaa.gov/cpo_pa/sarp/*. Although the findings of NOAA's research vary depending on the characteristics of the decision-making challenge at hand, this body of work underscores the potential value of climate information for decision-making, and the demand for climate information.

In addition. there are some overarching lessons that have been generated regarding the relationship between humans and climate, and the characteristics of effective decision support efforts that take uncertainty into account. Examples include the following:

- Climate forecasts are often just one tool utilized by decisionmakers in addressing a resource management challenge. Climate forecasts are not deterministic; the utilization of climate information by decision-makers requires a synthesis of science, practical resource management strategies and an anticipation of the requirements for the health and welfare of human society and the environment.
- Effective climate decision support systems include sustained processes for interaction and collaboration between the producers and users of climate informa-

tion. Users include decision-makers such as farmers, water managers, public health and safety managers and others responsible for managing climate-sensitive sectors.

- Climate information often requires specific tailoring before it can be utilized by users. For example. climate-based forecasts of total water volume might be useful for one type of water resource decision, but another type of decision might require information about the onset of seasonal precipitation.
- Communication methods must take into account the various levels of uncertainty associated with both the climate information and the context within which decisions are being made (*i.e.,* markets, culture, other environmental stressors).

Question 2b. How does NOAA plan to build on these efforts to assist the public and government decisionmakers?

Answer. The NOAA Climate Goal and its component programs are dedicated to providing the Nation with climate services through an "end-to-end" process (observations, analysis, prediction, application, delivery), and over all time scales. The NOAA Climate Program Office improves climate services through its five components:

- The Climate Observations and Analysis (COA) Program—The COA program's goal is to describe and understand the state of the climate system through integrated observations, analysis, and data stewardship.
- The Climate Forcing (CF) Program—The CF program's goal is to reduce uncertainty in the information on atmospheric composition and feedbacks that contribute to changes in Earth's climate.
- The Climate Predictions and Projections (CPP) Program—CPP program's goals are to provide (1) climate forecasts for multiple time scales to enable regional and national managers to better plan for the impacts of climate variability, and (2) climate assessments and projections to support policy decisions with objective and accurate climate change information.
- The Climate and Ecosystems (C&E) Program—C&E program's goal is to understand and predict the consequences of climate variability and change on marine ecosystems.
- The Regional Decision Support (RDS) Program—RDS program's goal is to build effective bridges between users and producers of climate information so that public and private sector decision-makers have access to and participate in the creation of new knowledge, processes, tools, and products to improve risk management, response, and mitigation in sectors sensitive to climate variability and change.

The National Integrated Drought Information System (NIDIS) is an example of an end-to-end process covering multiple time scale and climate program components. The vision for NIDIS is a dynamic and accessible drought information system that provides users with the ability to determine the potential impacts of drought and the associated risks they bring, and the decision support tools needed to better prepare for and mitigate the effects of drought. Implementation of NIDIS will require:

- Building a national drought monitoring and forecasting system;
- Creating a drought early warning system;
- Providing an interactive drought information delivery system for products and services, including an Internet portal and standardized products (databases, forecasts, Geographic Information Systems (GIS), maps, etc.); and
- Designing mechanisms for improved interaction with the public (education materials, forums. etc.).

Question 3. In your written testimony, on page 3, you list various types of assessment efforts that NOAA has been involved in. You do not mention that NOAA played an important role in the various sectoral, regional, and national components of the U.S. National Assessment, including leading the assessment of the likely impacts on coastal areas and marine resources and sponsoring several regional studies. Can you explain why the important results that emerged from these studies were not discussed in your testimony?

Answer. The work from the U.S. National Assessment report on coasts and marine resources is mentioned and cited in the testimony. For example, on page 4 of the testimony the summary article by Scavia *et al.* (2002) is referenced. Several studies cited in the U.S. National Assessment report (*e.g.*, Tynan and DeMaster,

1997; Brown, 1997) are also cited in the testimony. The U.S. National Assessment report on coasts and marine resources was published in 2000. The science on this topic is rapidly evolving. The testimony provides a synopsis of important recent findings, especially over the 6 years since the 2000 report was published on such topics as ocean acidification, which had not been well-studied at the time of the U.S. National Assessment.

Question 4. The regional, sectoral, and national results of the National Assessment formed the basis for the chapter on impacts and adaptation in the *U.S. Climate Action Report 2002* that was endorsed by all agencies before being submitted to the U.N. Framework Convention on Climate Change as the official government position. Have any recent scientific developments caused NOAA to reevaluate its positions regarding the potential consequences of climate variability and change, both based on the national level and for the regional and sectoral efforts that it led and/or sponsored?

Answer. Recent research results from prominent Earth system scientists are garnering considerable attention, particularly in the area of sea level rise, and potential trends in extreme events such as hurricanes, floods, and drought. These results warrant further attention, investigation, and dialogue across the Federal agencies and in partnership with Congress. For example, the experience over the past several years throughout the U.S. West with severe sustained drought has raised a broad range of issues ranging from drought management to assessing long-term drought trends, which have important implications for fire and water management, and ecosystem sustainability. NOAA is responding in the context of the development and cross-agency implementation of the National Integrated Drought Information System (MIDIS). We expect there will be more such calls for a range of climate information services responsive to the needs of local, state, and Federal managers.

Question 5. In your written testimony, you indicate on page 5 that "Remarkably only a few documented extinctions occurred in terrestrial and marine ecosystems during the ice age cycles . . . ." You indicate that one reason for this was likely that, overall, the climatic changes were "slow compared to the changes in the current millennium."

Given that the human influence has been primarily during the latter 20th century rather than over the entire millennium, would it be fair to say that changes during the last glacial period were very slow compared to the changes over the past 50 years, and that the rate of change might well be so fast that assurances that species survived glacial cycling likely provide no assurance that there will be remarkably few extinctions as a result of human-induced warming?

Answer. Yes, it would be fair to say that survival of many species during glacial cycling likely provides no assurance that there will be few extinctions as a result of human-induced warming. Two aspects of human-induced warming might cause species to become extinct in the future. One is the rapid rate of human-induced warming, roughly ten times faster than the rate observed in the paleoclimate record (the average Earth temperature warmed 4°C in a few thousand years at the end of the last Ice Age.[2] compared to the warming of 0.7°C in the past 100 years.[3,4] The second aspect is that climate is expected to reach conditions outside the range (of temperature, precipitation, ocean pH, and ocean and atmosphere circulation) experienced during the glacial cycles.[5,6] Unlike glacial times, future changes will occur in a world with 6 billion people within ecosystems now fragmented by human land use.

Question 6. A recent paper appearing in Nature (Grottoli et al.) indicates that a species of coral has been found that seems to be able to adapt to higher temperatures. In your testimony, you indicated that both the temperature increase and ocean acidification are threats to the coral. Is this newly identified species of coral also able to survive the ocean acidification that will be caused by the higher CO_2 concentrations?

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[2] Imbrie, J.I., E.A. Boyle, S.C. Clemens, A. Duffy, W.R. Howard, G. Kukla, et al. 1992. *On the structure and origin of major glaciation cycles: 1. Linear responses to Milankovitch forcing.* Paleoceanography. 7: 701–738.

[3] Jones, P.D., T.J. Osborn, K.R. Briffa, C.K. Folland, E.B. Horton, L.V. Alexander, et al. 2001. *Adjusting for sampling density in grid box land and ocean surface temperature time series.* Journal of Geophysical Research. 106: 3371–3380.

[4] Parker, D.E., C.K. Folland and M. Jackson 1995. *Marine surface temperature observed variations and data requirements.* Climatic Change, 31: 559–600.

[5] COHMAP Project Members 1988. *Climate changes of the last 18,000 years: Observations and model simulations.* Science, 241: 1043–1052.

[6] Houghton, J.T. et al. 2001. *Climate Change 2001: The Scientific Basis,* Cambridge University Press.

Answer. Grottoli *et al.*[7] found that one of the corals they studied, the branching coral *Montipora capitata,* was able to switch to feeding on zooplankton for its predominant food source. This allows it to better survive a bleaching event, but does not change its tendency to bleach. A recent study[8] on the impacts of elevated carbon dioxide on coral photosynthesis and calcification included *M. capitata* as part of the coral assemblage investigated. Although *M. capitata* appears to survive bleaching better relative to other corals[7] it is not immune from the effects of ocean acidification. Rather, *M. capitata* was found to exhibit a pronounced reduction in calcification rate in response to elevated carbon dioxide.

Question 7. In your written testimony you indicate that, apparently associated with an increase in air temperatures, "the density of krill . . . has decreased by more than 90 percent in the region since 1976" and that this is having associated impacts on other species. Is this evidence of a dangerous anthropogenic interference with one of nature's key ecosystems?

Answer. The reasons for the decline in krill populations in Antarctica are not clear and cannot be explained fully. Many factors are believed to have contributed to the declines. We know that the Southern Ocean is undergoing a warming trend, which likely influences ocean circulation and sea-ice dynamics. Although these factors likely affect krill populations, the definitive link between climate change and anthropogenic interference has not been established. Due to its relative isolation, the direct anthropogenic effects in Antarctica are substantially less than in other parts of the world. It also is clear that the decline in krill populations is not directly related to overfishing. The present annual harvests in Antarctica are around 100,000 tonnes, while the International Commission for the Conservation of Antarctic Marine Living Resources precautionary catch limits are more than 4 million tonnes. The catch limits are based on relatively recent surveys. There is considerable debate in the scientific community concerning the role indirect effects may have played in this ecosystem. As my testimony indicated, reduced sea ice is generally believed to have played a major role in reduced krill populations. Other causal effects are difficult to quantify. Evidence suggesting anthropogenic interference with the Antarctic ecosystem is not clear and considerable debate exists among scientists. We are addressing these concerns, but it will be some time before cause and effect is clearly delineated.

Question 7a. If not at 90 percent, at what point would it be that NOAA management would strongly advocate publicly and with the Administration for actions to slow and limit further changes in the climate?

Answer. NOAA will continue to carry out our mission to "understand and describe climate variability and change to enhance society's ability to plan and respond" through our research, observations, and modeling capabilities, but we do not focus on advocacy. As a key part of the U.S. Climate Change Science Program, we are working on developing synthesis and assessment products intended to provide the best possible scientific information, developed by a diverse group of climate experts, for the decision community. These reports are designed to address a full range of scientific questions and evaluate options for responses that are of greatest relevance to planners and decision-makers.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON FRANK R. LAUTENBERG TO DR. SYUN-ICHI AKASOFU

I am glad to have this opportunity to express my thoughts on the global warming issues in more detail, since it was not easy to do so during the testimony due to the time constraints. I have tried to answer all your questions.

If you have further questions, please do not hesitate to contact me. Also, I am more than happy to explain more when I come to Washington, D.C., next time.

Question 1. Regarding Figure 1 in your written testimony—Why is it that the graph indicating sources of energy ends at 1985 and does not show the associated increase of energy use with temperature up to the present?

Answer. I received the invitation to testify while I was in Tokyo and had only a few days to prepare the written document by working with my staff in Fairbanks, Alaska, via phone and fax. The original Figure 1 in my testimony was prepared under these difficult circumstances.

[7] Grottoli, A.G., L.J. Rodrigues, and J.E. Palardy. 2006. *Heterotrophic plasticity and resilience in bleached corals.* Nature. 440: 1186–1189.

[8] Langdon, C., and M.J. Atkinson. 2005. *Effect of elevated* pCO_2 on photosynthesis and calcification of corals and interactions with seasonal change in temperature/irradiance and nutrient enrichment. Journal of Geophysical Research—Oceans. 110(C9): C09S07.

Question 1a. Could you please provide an updated plot that extends the energy record to at least the year 2000, or preferably extends both the emissions and temperature records to 2005?

Answer. I am glad to have an opportunity now to provide you with an updated version of Figure 1, which is now Figure A in this correspondence. I also prepared a new one with the CO_2 data alone (Figure B), which I wanted to use to begin with. Please notice that the range of temperature changes is much greater in the Arctic than the global average provided by the IPCC Reports.

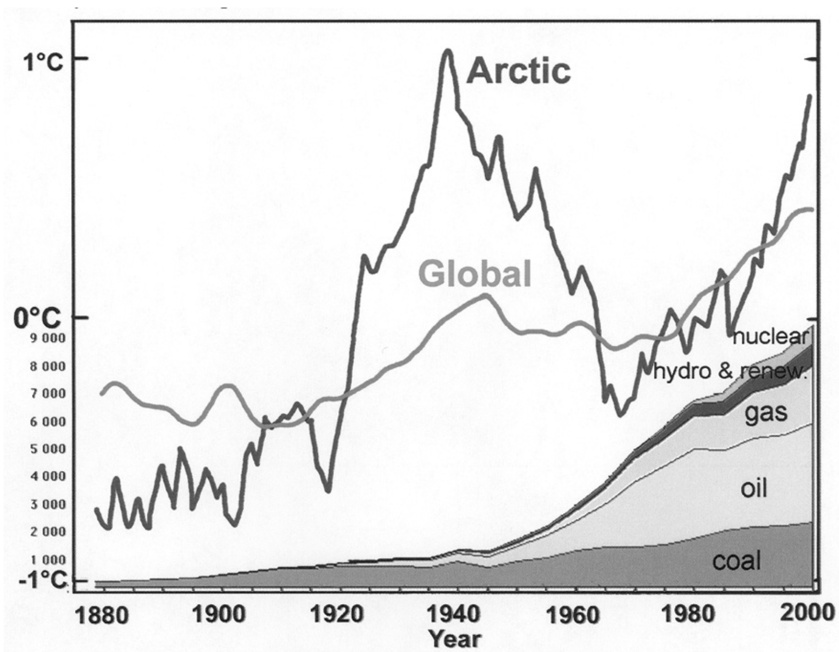


Figure A

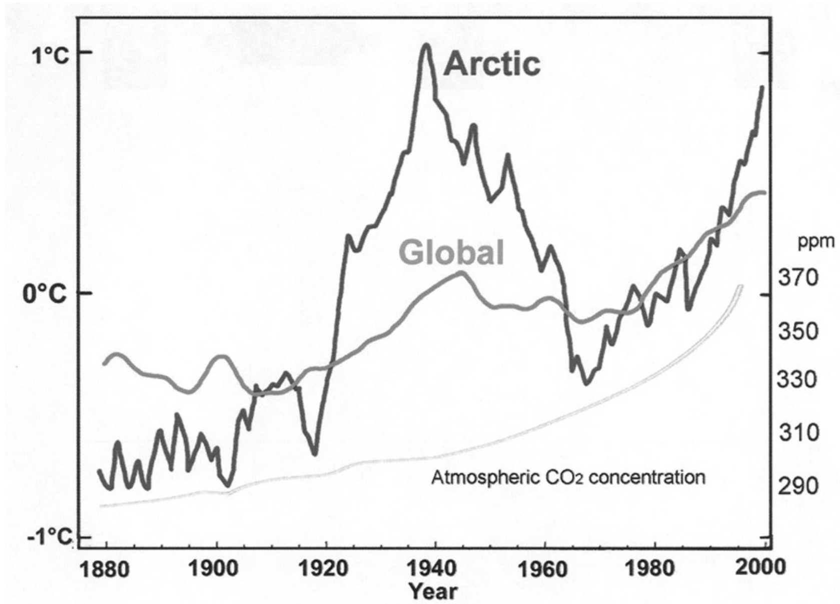


Figure B

Question 2. In Figure 1, is the mid–20th century jump (*i.e.,* increase and then decrease) in the Arctic temperature record that you show a usual occurrence; that is, is there any indication that such sudden and short duration warming periods have occurred previously?

Answer. Before 1850 or so, there were not many thermometers in the whole world. Therefore, we have to rely on proxy data. Unfortunately, a 1000-year temperature record based on the tree ring analysis by Mann (the so-called 'hockey stick') used most frequently and prominently in IPCC Reports and others, is now very controversial; please see your item 7.

The most reliable data for the past are deduced from ice cores (O18). We are fortunate to have such a high-resolution (in time) data from Severnaya Zemlya (Figure 5 in my testimony, which is reproduced here as Figure C). There have been a number of fluctuations, large and small, superposed on a linear increase (which is discussed in conjunction with your Item 8).

Please note that the top, middle, and bottom traces agree reasonably well, confirming the accuracy of all the data shown.

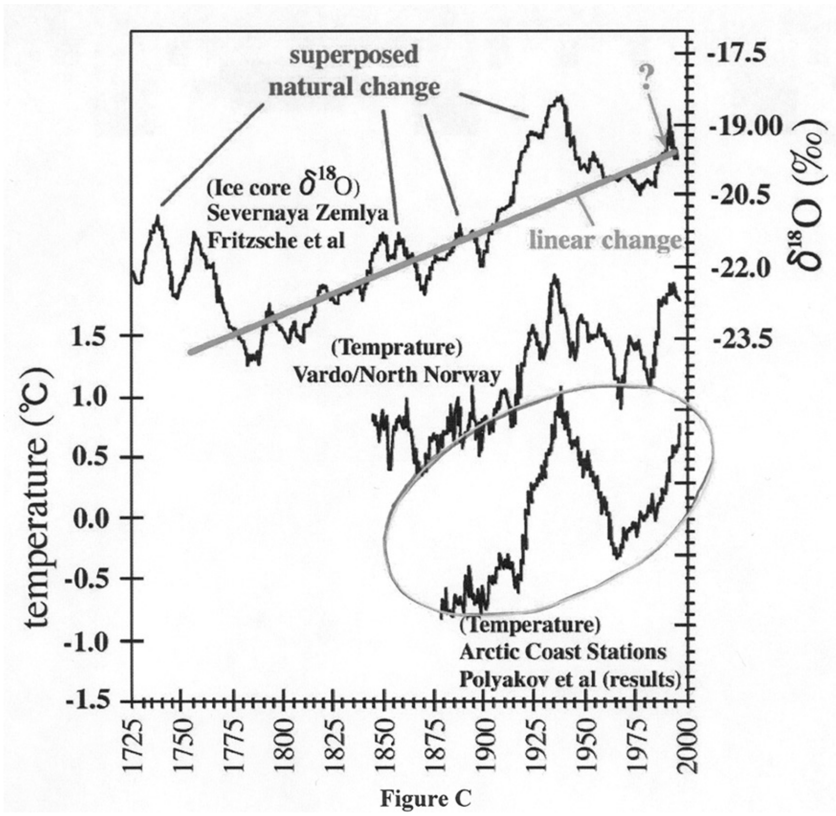


Figure C

Question 3. Might there be problems with the data set that is used to generate this record, especially given the limited time over which observations are available in the Arctic? Could you supply some indication of the number of measurements going into the Arctic record and the percentage coverage of the Arctic that is represented over time by this record?

Could it be that only one part of the Arctic was as warm in the mid 20th century as it is currently and other parts that did not warm were not represented in the temperature record of Polyakov?

Answer. The top of Figure D shows the same temperature record as that of Figure A (or Figure 1 of my testimony). Please note that added to it, as an insert, is the distribution of the stations from which data was used. They are distributed mostly along the entire arctic coast. (Russia actually kept excellent temperature records even in Siberia and recorded carefully watched changes in natural phenomena, better than some other places in the world.)

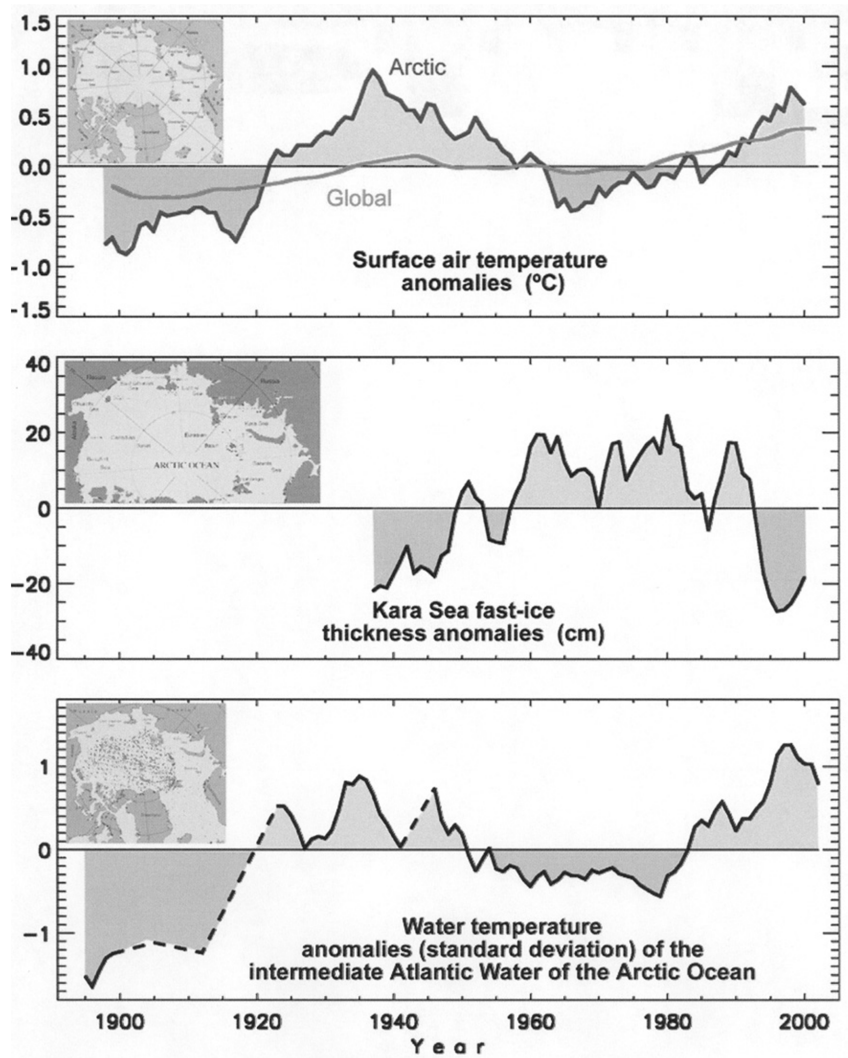


Figure D

The bottom of Figure D shows sea water temperature data. They are taken from the middle of the Arctic Ocean as the insert shows.

Please note that the temperature record similar to figure A is shown on page 23 of the ACIA Report "Impact of a Warming Arctic" (Figure 4 of my testimony); it includes continental data in the Arctic. It shows a larger increase after 1970 than in 1940, because a very prominent warming occurred in the continental Arctic, which is disappearing during the last decade or so, as shown in Figure 3 of my testimony.

Question 4. With the Arctic indicated to be as warm in the mid–20th century as at present, and with that warming lasting for a time comparable to the time of the current warming, is there evidence that indicates that the same types of changes in sea ice, permafrost, glacial melting, species shifts, etc. occurred as we are seeing at present? Do the Indigenous elders recall such warm periods and the appearance of the new birds and other species that are now occurring in the Arctic?

Answer. Sea ice: The only reliable, long-term data before 1950 are observations of the southern ice edge in the Norwegian Sea (Figure E; my testimony Figure 7b).

Please note that the range of changes during 1920–1960 (corresponding to what you term 'the mid-20th century jump' was much larger than the present change after 1970; the present change is much smaller than that during the mid-20th century in the Norwegian Sea. Please note also a linear change similar to the ice core change that will be discussed in your Item 8.

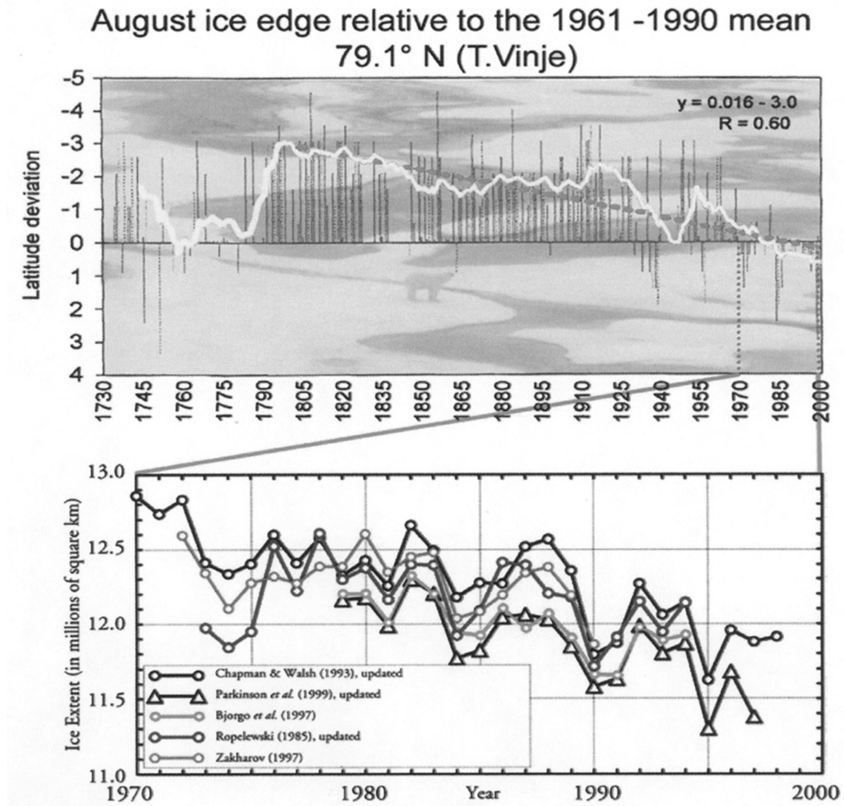


Figure E

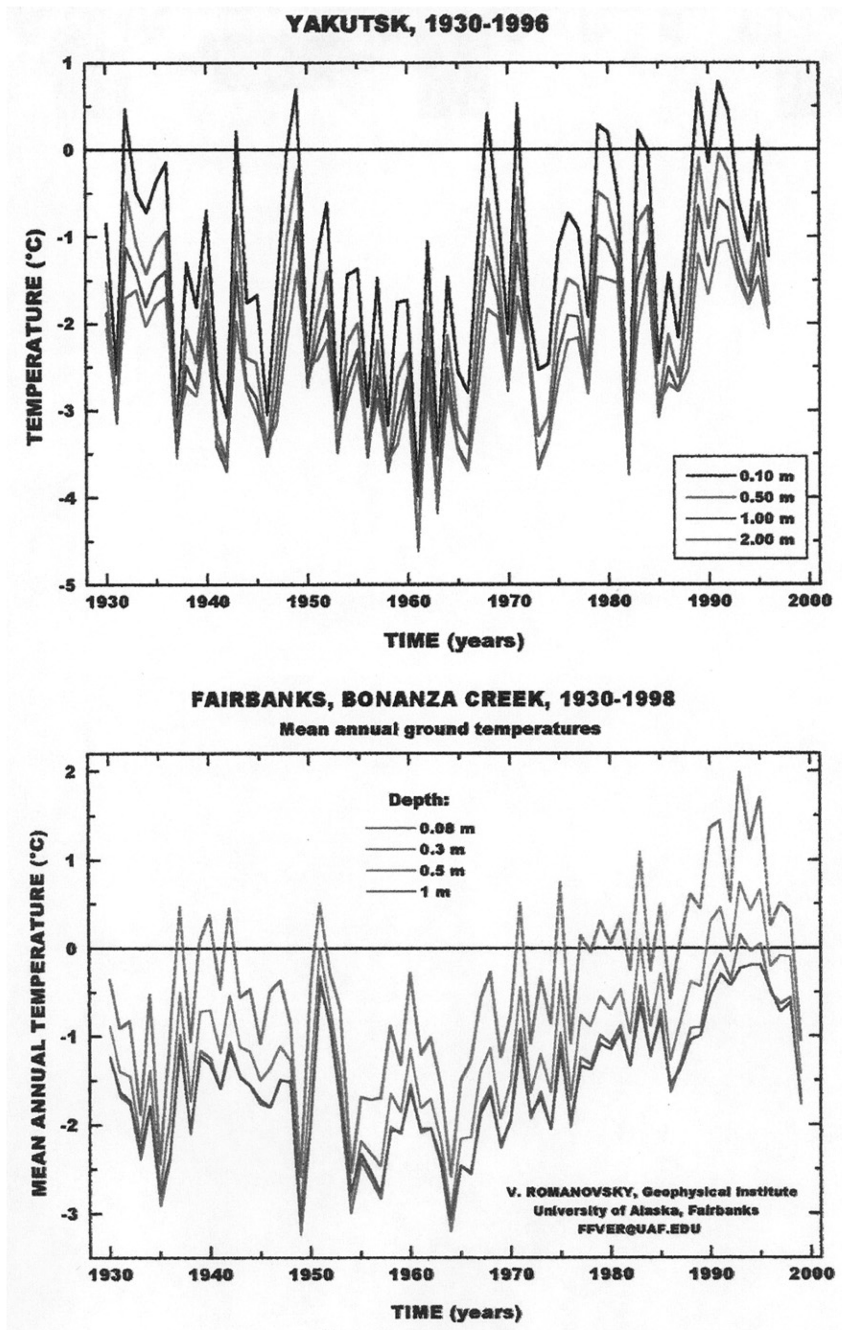
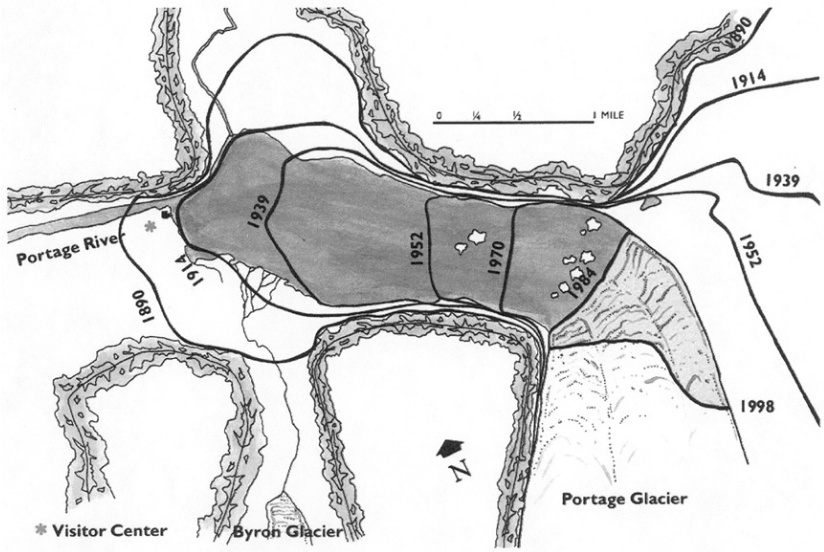


Figure F

Permafrost: Figure F shows the best available temperature data on permafrost, from both Siberia and Fairbanks. Please note that the temperature was decreasing

until 1970, in spite of the fact that the amount of CO_2 began to increase rapidly in about 1940. Permafrost temperature closely follows air temperature (please compare Figure F with Figure A).

Glaciers: Old Russian records show that many Alaskan glaciers have been receding since 1800 or earlier (Figure 7a in my testimony). The recession did not start in 1970; please see also Figure G. Changes in the European Alps are similar to it.



The retreat of Portage Glacier (Chugach National Forest).

Figure G

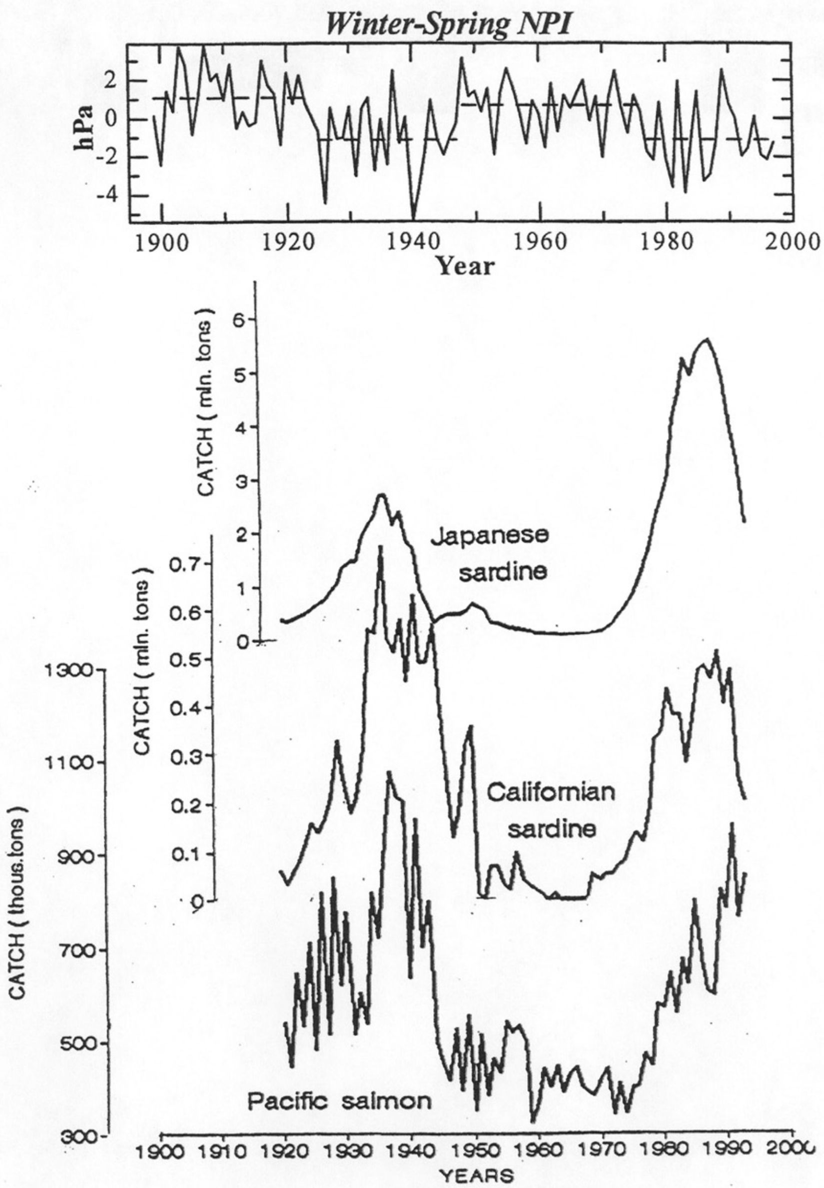


Figure H

Many recent TV programs show large blocks of ice falling off the glacier terminus, implying that this phenomenon is a manifestation of global warming. Most people do not realize that glaciers are actually "rivers of ice" (where *ice flows*) and that ice has been falling off glacier termini for thousands and thousands of years.

Others: Some species are obviously quite sensitive to temperature changes; fish are quite sensitive to sea water temperature changes. I am not an expert on such issues, but happen to have an interesting figure (Figure H), which shows changes

of fish populations in the Pacific. It seems that such changes are a common occurrence.

Question 5. In your written testimony you state that "It is also important to note that both the Arctic and global temperatures began to decrease in about 1940, when our release of greenhouse gases began to increase rapidly. Thus the increase-decrease between 1920 and 1970 must be natural change." The most often mentioned natural factors that could be responsible for a warming are a reduction in the amount of volcanic aerosol and an increase in solar radiation. If these factors are indeed responsible for this warming, it would seem to lead to the conclusion that the Arctic climate is very, very sensitive to slight changes in the amount of energy driving the climate system, in that the volcanic and solar influences, in terms of Watts per square meter, have been relatively small. Thus, should not your assertion that these changes are natural make us very, very concerned about the climatic changes that lie ahead given the large changes in atmospheric radiation being caused by the continuing human-induced increases in the concentrations of greenhouse gases?

Question 6. The detection and attribution studies reported on by the IPCC conclude that the warming prior to about 1940 was likely due partly to natural factors and partly to the release of greenhouse gases, and that the subsequent cooling was due mainly to the increasing emissions of SO_2 and possibly a slight diminution in solar radiation and return of volcanic eruptions. These carefully done detection and attribution studies, endorsed by the IPCC, make clear that such analyses must include consideration of all forcing factors (and that there are natural and human-induced factors that induce warming and other factors that can induce cooling). It therefore seems to be quite a jump to suggest that the mid-century part of the record must be entirely due to natural factors without considering the human influences also likely to have exerted influences throughout the 20th century. What steps does your analysis take to conclude that the full set of human-induced factors is not having an influence?

Answer to Questions 5 and 6. I believe that all the IPCC GCMs consider effects of observed volcano effects (past major eruptions), solar output changes, aerosol effects (SO_2), etc., and their positive/negative feedback effects as well, *quantitatively* with the *best knowledge available.* However, they cannot reproduce the mid–20th century jump. It is very hard to explain the 1940–1970 decrease, particularly since CO_2 began to increase rapidly at that time; the initial increase is also hard to explain. Therefore, at this stage, I must come to the same conclusion I did earlier during my oral testimony, as I describe below again.

We always come up with interesting ideas about how to explain natural phenomena, but if they fail the quantitative tests, we have to abandon them. This happens every day in science. If the idea has failed the test and knowing that the test was conducted with the best knowledge available at the time, scientists should not pretend or claim that their interesting ideas are still alive. Such interesting but unproven ideas belong to science fiction. During my testimony I showed that the continental arctic warming during 1970–2000 belongs to that category (Figure 2 of my testimony), too. Nothing is 100 percent certain in climatology, but I believe that the Senate subcommittee members did not want 'noncommittal' statements from the panel members. On the other hand, if the idea passes the test, I am happy to support the idea. Since I am not a climatologist, I have no hang-up in either camp. What I can say as an auroral physicist is that the present climatology is very abnormal.

As you may know, the "mid-20th century jump" is a northern hemisphere phenomenon, not a southern hemisphere phenomenon. Thus, it is NOT A GLOBAL phenomenon. This is very clear in the paper by Jones, which became the basis of the IPCC Report. In fact, it appears to be a phenomenon above 40° latitude in the northern hemisphere, so that it is doubtful that it is really a global phenomenon. It may well be that this is why the GCMs cannot reproduce it as the greenhouse effect! (Just as is the case of the continental arctic warming!)

Some people argue that the GCMs have not advanced enough to be used for such tests. If so, they would logically also have to doubt the basis of the Kyoto protocol on global warming. There may be some problems with prediction, because we have to assume the amount of CO_2 released in the future. On the other hand, we are using GCMs for what we call "hind-casting" based on the observed CO_2 data, and the GCMs are accurate enough for our purpose; furthermore, we are using 14 GCMs.

Question 7. You indicate on page 1 of your written testimony that "It is incorrect to conclude that the present warming in the Arctic is due entirely to the greenhouse effect caused by man." In answer to a question, you indicated that such assertions

were being made mainly by the media and did not indicate any scientific assessments that were making this assertion. Is it your opinion, therefore, that we can rely on the IPCC and ACIA assessments, even though there may be some misimpressions given by some in the media, or are you suggesting that the assessments are also flawed?

Question 7a. If the latter, please provide specific examples where you think the complete picture is not being presented. What part of the warming do you judge to be human-induced and what fraction natural, and what is your estimate of how this ratio has changed over time?

Answers to Questions 7 and 7a. Both the IPCC and ACIA Reports served in raising awareness of the CO_2 problem. However, I am not very happy about the "tactics" they used (you must have heard about some of the complaints from the contributors). There was no "refereeing" like scientific papers for scientific journals. During our testimony, Dr. Reiter was quite critical of one chapter on malaria, saying that the contents was very poor. You will recall that this was also a major complaint by Dr. Michael Crichton during his testimony in one of the earlier hearings. As I also mentioned in my testimony, the present climate research presented by the IPCC Report is not taking the normal scientific practice. For example, Mann's "hockey stick" figure was so appealing for the purpose of raising awareness of the greenhouse effect, it was prominently used by the IPCC Reports. Mann's figure shows neither the Medieval warming nor the Little Ice Age, so that some scientists questioned its accuracy. Finally, two Canadian experts in statistics analyzed the same data (which they said Mann was very reluctant to make available; as you may know, Congress finally demanded he submit the data) and showed that there is no "hockey stick" in the data (Figure I). I am afraid that Mann's results, the IPCC "flagship," may turn out to be a flawed case. Dr. Robert Correll used it in his testimony without telling us that there is some problem with it, even if he believes its accuracy. It is unfortunate that it gave the impression that the greenhouse effect did indeed take off.

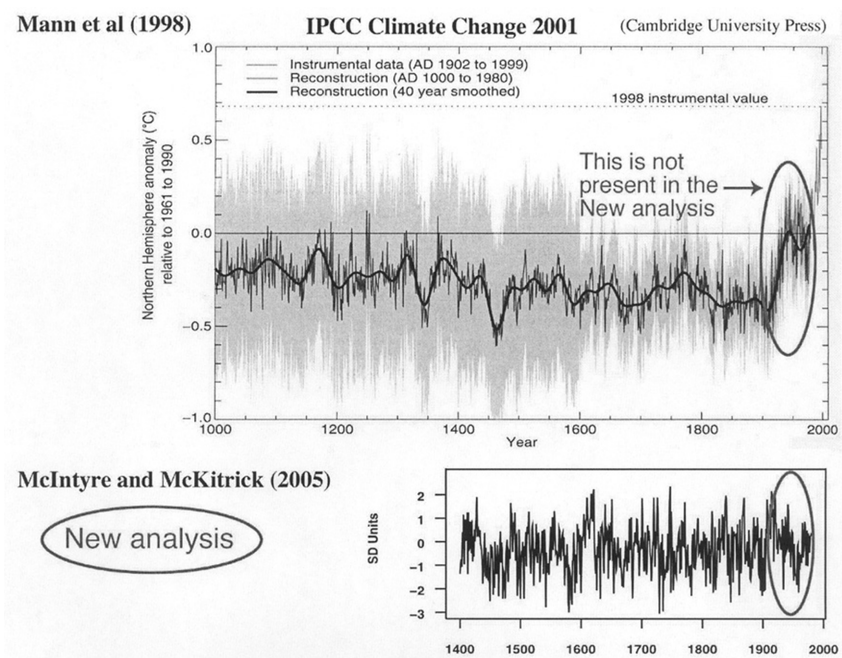


Figure I

In science, new results should be scrutinized by the community, and if they survive the scrutiny, they become scientific facts. It is my belief that the IPCC way of mobilizing hundreds of scientists is not a good practice in science. I wonder how many of the IPCC contributors can defend Mann's work, in spite of the fact that they are the co-authors.

Another important issue: as I testified, many climatologists use satellite data, which became available only in the 1970s, when the latest rise in temperature occurred. Therefore, what they report is naturally related to the temperature rise. Many of the presently active scientists were born in the 1960s and 1970s, so that it is natural for them to assume that the temperature rise has been happening during their whole life. However, in terms of genuine climatology, it is but an instant. That is why I want to call them "instant climatologists"; many of them do not want to work on the mid-20th century jump, since it will take a great deal of effort to get data similar to what satellites can provide readily. In order to work on climatology, I am asking my colleagues that they should try to get at the very least data that spans a few hundreds years. Climatology used to be like anthropology. However, after the advent of satellites and computers, it has become an instant climatology.

Now, the present problem is that the media and many special interest groups take the scientific data after the 1970s as scientific fact for the greenhouse effect. As soon as results associated with the rising temperature are reported in scientific papers (or even before), they are immediately reported by them as scientific facts proving the greenhouse effect, confusing the term global warming as synonymous with the greenhouse effect. Many media people do not have enough scientific background on the greenhouse effect. I might add that scientists who doubt or criticize greenhouse studies are demonized by the media these days. All this is a very abnormal circumstance in science, I am afraid. Whenever an issue is raised, the media defends itself by saying that hundreds of scientists joined in the preparation of the IPCC Reports. I hope you can understand the problem.

Distinguishing between natural and manmade components of climate change is a very difficult task, but IARC scientists are challenging the problem, since this is the one way to "reduce uncertainty in climate change predictions"; please see your item 8.

Question 8. In your Figure 7b (top) you include a linear trend line beginning in 1760 and going to the year 2000. Why do you assume that human-induced influences should be linear, especially given the temporal and spatial variations in the forcing terms, interactions these might have for the atmospheric and oceanic circulations, etc.?

Answer. The linear line in Figure C is NOT meant to be human-induced influence at all. It is only recently that the ice core (O18) analysis provided us with proxy data for the last 200 years. The longer the analysis period is, the more accurate the baseline becomes, on which various fluctuations are superposed. In the 100-year data (Figure A), we could not see clearly the linear trend (the ACIA Report, p. 23, used the 100-year average value as the baseline). There is little doubt about the presence of the linear trend in the 200-year data.

As you correctly observed, there is no way to explain the linear trend by the greenhouse effect. I speculate that it is a natural change; the sea ice data and some other O18 data show similar linear trends. Are we still recovering from the Little Ice Age?

IPCC Reports say that the global temperature increased by 0.6°C during the last century, and it implies that the increase is caused by the greenhouse effect. If the linear change continued until recently, and if it were indeed to be natural change, the greenhouse effect will not be a large fraction of the 0.6°C. This is the uncertainty we have to face in climate change research at the present time. We have to isolate the linear trend and other natural changes in detail and find out the real contribution of the greenhouse effect.

Question 8a. Might it be that conditions continue in one state for a while and then flip, for example, once the ice melt reaches a certain amount or once temperatures in key regions exceed the freezing point?

Answer. What you are referring to may be what we call the "threshold" point. For example, many researchers told me earlier that sea ice in the Arctic Ocean off the Alaskan coast had crossed "the point of no-return" during the summer months based on satellite data. However, sea ice was much closer to the Alaskan coast in 2005 than in 2004 or 2003. It came back last year.

In principle, what you say may occur; however, I am not sure if the present climatology can predict accurately the threshold point of any climate change phenomena.

Question 9. Although climate models may not provide sufficiently accurate representations of the spatial distribution of warming, do you agree that they do include representations of the overall thermodynamic and dynamic influences, so that the global integral of the influence, which is presumably based on the overall balance of energy, of increasing concentrations of greenhouse gases, and of other fac-

tors is roughly correct? What improvements do you think are most needed in the available climate models?

Answer. The physics of the greenhouse effect is sound and clear; that is not the question. The questions are: (1) how much did the greenhouse effect contribute to the 0.6°C increase and the mid-20th century jump, and (2) how much will the temperature increase by 2100, more than 6°C or less than 1°C? (When I say this, some scientists immediately argue with me and say that I deny the greenhouse effect. They forget the normal scientific practice, and the IPCC must have created such an unscientific atmosphere.)

At the International Arctic Research Center (IARC), our main objective is to "reduce uncertainty in future climate change predictions." Certainly, our progress in science will improve the modeling effort. On the other hand, we should not forget that the Earth's temperature fluctuates all the time. We cannot understand the cause(s) of the Big Ice Age, the Medieval warming (1000–1300 AD, almost as warm as the present time), and the Little Ice Age (1400–1900?), in addition to the fact that the temperature was higher at the beginning of the present interglacial period and some other interglacial periods when only anthropoids were present on Earth. This is what Dr. Thomas was stressing during his testimony. There is no reason to assume that the linear change suddenly stopped after 1900. We have to identify and subtract natural change from the on-going changes; the rest will give us some idea about the greenhouse effect.

I am afraid that this communication is getting too heavy, so that I have put two cartoons at the end. I find that cartoonists observe well the present situation.